A-1625

FINAL TECHNICAL REPORT

OWEX II RADAR TESTS

EES/GIT PROJECT A-1625

By

George W. Ewell

Prepared for

NAVAL UNDERSEA CENTER
Code 503
San Diego, California
Under
Contract N00123-74-C-2048

June 1975

1975

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30332

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SUMMARY

This report summarizes efforts carried out by the Engineering Experiment station at Georgia Tech in support of the DARPA Ocean Wave Experiment (OWEX). The report concentrates on the radar equipment furnished for the experiment, and the characteristics of the resulting data. Detailed analysis of most of these data is not covered in this report, since this was handled by another organization.

This report first discusses the 9.5, 16.5, 35, and 95 GHz radars used during the experiment and the data acquisition systems used to record data. The data verification and calibration procedures are then discussed, and some representative data are reviewed. A portion of the data include some original observations concerning the upwind-downwind-crosswind behavior of radar sea clutter and representative sea clutter behavior for a range of environmental conditions. The report concludes with recommendations for improvements in both equipment and procedures for any future experiments.

ACKNOWLEDGMENTS

The completion of this experiment was possible only through the combined efforts of numerous people at several organizations. While it is impossible to name all of the people involved, particular recognition should go to Dr. R. F. Hoglund of DARPA, Mr. Dale Good of the Naval Undersea Center (NUC), and Dr. F. L. Fernandez of R&D Associates for their comprehensive planning of the complete experiment. The efforts of Dr. R. W. Ziemer of RDA, and Mr. N. E. Brake and Mr. J. C. Butterworth of EES in conducting the field operation were vital to the successful completion of the measurements. Finally, the contributions of Dr. D. E. Wrege, Mr. C. L. Hilbers, and Mr. A. W. Jordin of EES were essential to the success of the program, and are gratefully acknowledged.

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I. INTRODUCTION

This report discusses efforts carried out by the Georgia Tech Engineering Experiment Station (EES) under Contract N00123-74-C-2048 for the period from mid-April 1974 through June 1975. This program was funded by DARPA through the Naval Undersea Center (NUC), and provided support for the DARPA Ocean Wave Experiment program (OWEX). The object of this program was to determine if internal waves affect radar reflectivity of the ocean surface, and to correlate any such variations in radar reflectivity with a number of environmental measurements.

These radar measurements complement and extend an earlier set of measurements performed at the NUC tower, San Diego, during 1972. The current measurement program extends the radar measurements to higher frequencies, allows different look directions relative to the propagating wind/wave direction, allows higher accuracy and resolution of recorded data, and samples data from a larger range extent than the previous experiments. In addition, more extensive environmental instrumentation was employed during these experiments, permitting spatial correlation and direction of the internal waves to be accurately determined. The radar measurements and a portion of the environmental data recording were carried out by EES, while the environmental and internal wave instrumentation was the responsibility of the Naval Undersea Center: detailed data reduction along with overall experiment planning and supervision were the responsibility of R&D Associates, Inc. (RDA).

The radar-related data which were acquired during these experiments were of two general types. The first consisted of data from twenty contiguous range gates, each having approximately a 50-nsec width, which were collected from each of four different radar video signals. These were averaged and recorded, along with eight environmental inputs, on digital magnetic tape. The other type of radar data taken consisted of pulse-by-pulse recordings of the return signal at a single range gate for each of the four radar inputs. The first data were principally used for determining the long-term characteristics of radar reflectivity which were influenced by the presence and passage of internal waves. The second type of data was taken to permit determination of such sea-surface characteristics as amplitude distributions, frequency spectra, and auto-correlation functions. In addition, the pulse-by-pulse data acquisition system was also used to investigate the detectability of "chaff" floating on the water surface.

Preparation of equipment at EES began during the latter part of April 1974, and the radar equipment was shipped from EES on 6 July 1974. The radar equipment arrived at NUC on 8 July 1974, and after several unsuccessful attempts, it was finally loaded on the NUC tower on 5 August. The computer used to acquire some of the data was not delivered to EES until the first of August; the computer program was written and de-bugged in less than two weeks, and the computer arrived in San Diego and was loaded on the NUC tower on 15 August. The first preliminary data were acquired on 16 August and data recording continued on a regular basis through September 24th, with no interruption due to equipment problems. Shortly thereafter the equipment was removed from the NUC tower and returned to EES. Efforts from October 1974 through June 1975 have been largely concerned with reduction, calibration, and verification of these recorded data, furnishing of copies of data to RDA, and general support of the more detailed analyses being conducted by RDA.

A large amount of data was recorded during these operations. Average-value data were recorded for approximately 203 hours, and supporting these data were approximately 188 runs of pulse-by-pulse information with pulse-by-pulse data intervals ranging in duration from 2 to 20 minutes. In addition, eight channels of environmental information were recorded for all the average-value data intervals.

The following sections of this report discuss a number of aspects of the experiment in much greater detail. Section II discusses the specific equipment used during this experiment, while the third section discusses data verification and calibration procedures used, along with some specific problem areas encountered during the course of the experiment. The fourth section of this report discusses some representative data taken during the field operation, while the fifth section presents conclusions and specific recommendations for improvements in equipment and procedures in any similar operations that might be carried out in the future.

II. DATA ACQUISITION EQUIPMENT

The equipment assembled for this test consisted of the radar equipment itself, the average-value data-acquisition system, and the pulse-by-pulse data-acquisition system.

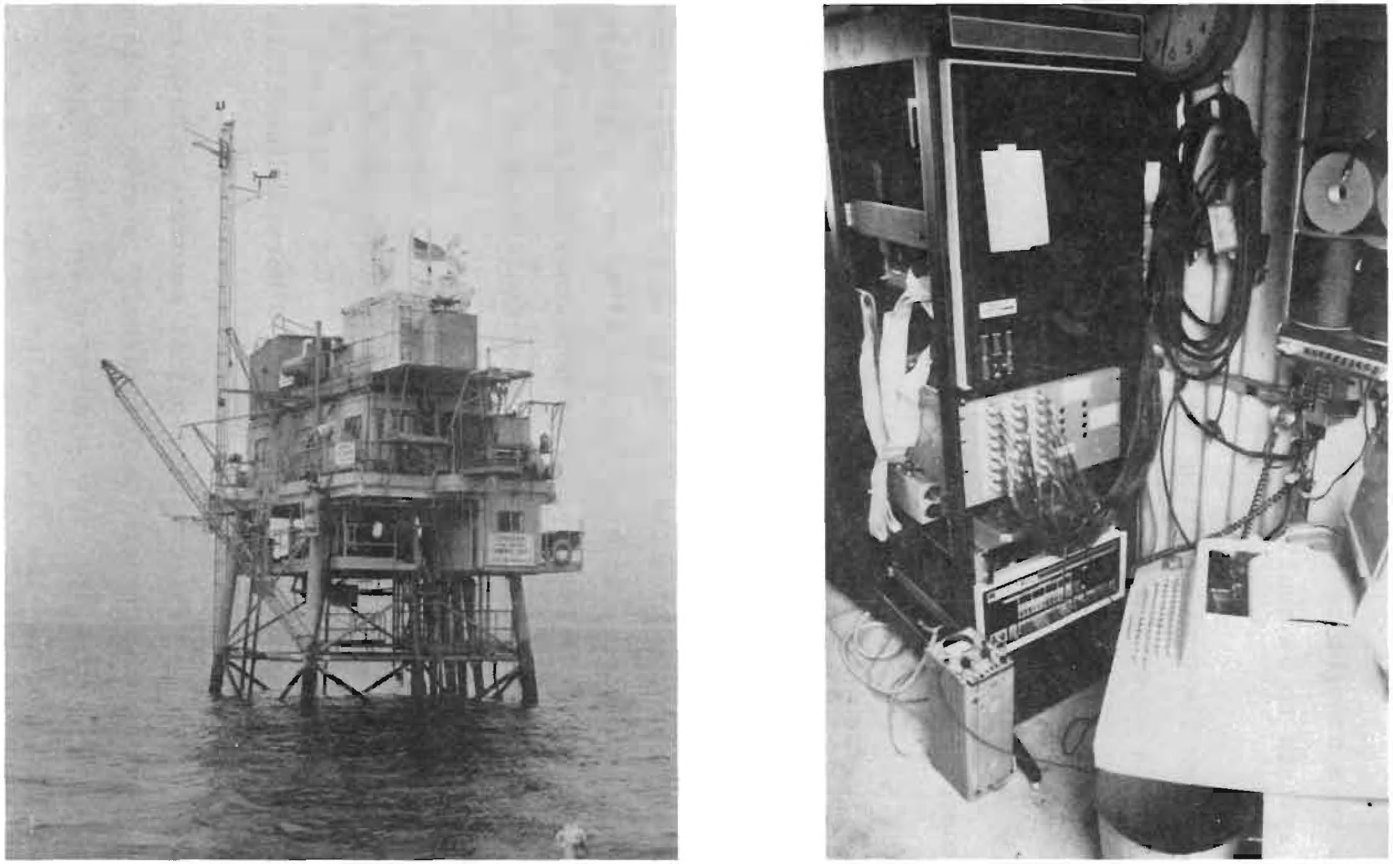
A. Radar Equipment

The radar equipment assembled for these operations consisted of four systems operating at frequencies of approximately 9.5, 16.5, 35, and 95 GHz. Parameters of these four systems are summarized in Table I. The three lower-frequency systems were mounted in the container on the back of a 2-1/2 ton truck; for this experiment, the container was removed and transported to the NUC tower off San Diego, California. The 95-GHz system was configured in a self-contained box and mounted on top of the van when in use. The 95-GHz system receiver triggers from, and sent data to, the integrated data-acquisition equipment located in the container. Figure 1 shows the radar equipment installed on the NUC tower, and the average-value data acquisition system installed in a room on the main level of the tower.

While differing in detail, the 9.5, 16.5, and 35 GHz systems are similar. They are all relatively short-pulse systems and all are dual-polarized, that is, they receive horizontally and vertically polarized returns simultaneously while transmitting either horizontal or vertical polarization. While they may be operated in either scanning or non-scanning modes, the non-scanning mode was used for these experiments. All incorporate logarithmic receivers of wide dynamic range (approximately 80 dB) to permit accurate measurement of returns from targets having widely varying signal strength, and a linear receiver was also available for accurate measurement of small changes in return. Each of these systems incorporates provision for injection of known calibration signals into both the parallel- and cross-polarized channels. Signals

TABLE I
Radar Parameters for OWEX.

PARAMETER	VALUE			
BAND	9.5 GHz	16.5 GHz	35 GHz	95 GHz
FREQUENCY	9.5 GHz	16.5 GHz	35 GHz	95 GHz
PEAK POWER	40 kW	50 kW	25 kW	6 kW
PULSE WIDTH	50 ns	50 ns	50 ns	50 ns
PRF	0-4000 pps	0-4000 pps	0-4000 pps	0-4000
ANTENNA TYPE	SCANNING PARABOLIC CYLINDER	SCANNING PARABOLOID	SCANNING PARABOLOID	PARABOLOID (CASSEGRAIN)
SCAN RATE	0-1000 rpm	0-120 rpm	0-120 rpm	0 rpm
AZIMUTH BEAMWIDTH	2.0^{o}	1.5^{o}	1.0^{o}	0.70^{o}
ELEVATION BEAMWIDTH	5.0^{o}	1.5^{o}	1.0^{o}	0.65^{o}
ANTENNA GAIN	35 dB	41.4 dB	43.1 dB	47.1 dB
POLARIZATION	H OR V TRANSMIT, H AND V RECEIVE SIMULTANEOUSLY	H OR V TRANSMIT H AND V RECEIVE SIMULTANEOUSLY	H OR V TRANSMIT H AND V RECEIVE SIMULTANEOUSLY	H OR V TRANSMIT AND RECEIVE
IF CENTER FREQUENCY	60 MHZ	60 MHz	60 MHz	60 or 160 MHz
IF BANDWIDTH	20 MHz	20 MHz	20 MHz	20 or 100 MHz
IF RESPONSE	LOGARITHMIC AND LINEAR	LOGARITHMIC AND LINEAR	LOGARITHMIC AND LINEAR	LOGARITHMIC AND LINEAR
NOISE FIGURE	12 dB	13 dB	14 dB	10 dB
DYNAMIC RANGE	80 dB	70 dB	70 dB	70 dB
DISPLAY	A-SCOPE, B-SCOPE, PPI	A-SCOPE, B-SCOPE, PPI	A-SCOPE, B-SCOPE, PPI	A-SCOPE, B-SCOPE PPI
INSTALLATION	MOBILE VAN	MOBILE VAN	MOBILE VAN	PORTABLE CASE



(a) Tower with radars installed.

(b) View of average-value data acquisition system installed on tower.

Figure 1. Equipment installed on tower for the OWEX.

and functions were brought to front panel connectors, permitting a number of different systems to be configured by recabling these front panel functions.

Figure 2 shows the configuration for the three lower-frequency systems as used in the OWEX experiments, showing the provision for injection of calibration signals and for taking simultaneous parallel- and cross-polarized information. Often, more than one system would be configured in this manner and the transmitters pulsed simultaneously, permitting truly simultaneous multi-frequency pulse-to-pulse measurements to be performed.

The 95-GHz radar which was used for the OWEX is an instrumented, calibrated short-pulse measurement radar. The radar is housed in a small, protective container which consists of two separate compartments; one containing the magnetron and modulator, and the other containing the receiver. The packaging approach combines the desirable level of isolation of the functions needed to minimize interaction and interference problems with good portability and accessibility. This container was mounted on the van for the OWEX experiments. The overall system configuration is shown in block diagram form in Figure 3.

The 95-GHz system is changed from horizontal to vertical polarization by physically rotating the primary feed of the Cassegrain antenna. This antenna produces a 0.7° far-field pencil beam. For "searchlight" measurements, the antenna beam was aimed with a boresighted rifle scope.

The 95-GHz system is configured to permit accurate acquisition of carefully calibrated reflectivity data: a logarithmic receiver of large dynamic range (typically 70 dB) was used for pulse-by-pulse recording, and a linear receiver was used for the average value data.

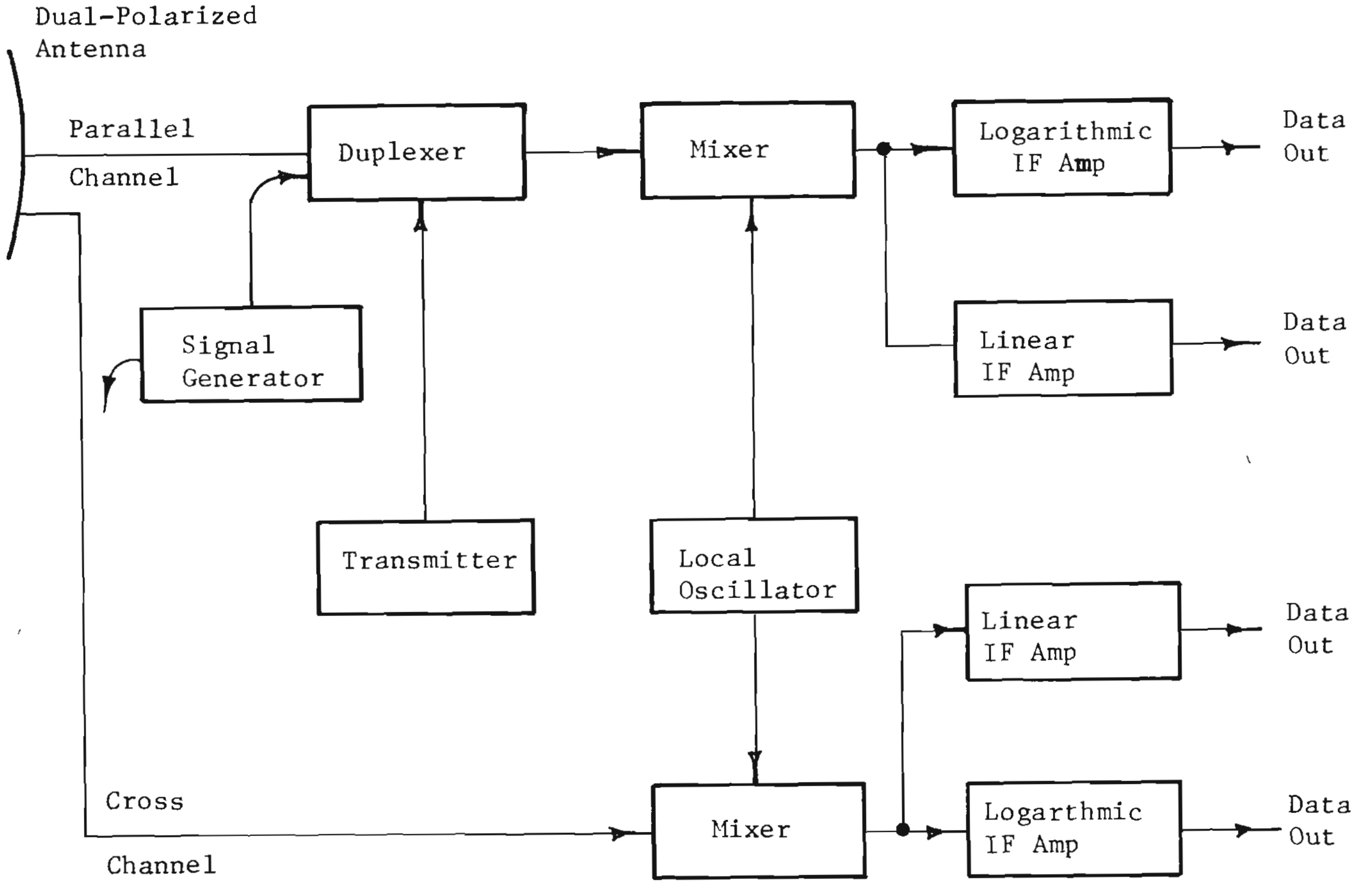


Figure 2. Simplified block diagram of 9.5, 16.5, and 35 GHz radars as configured for OWEX.

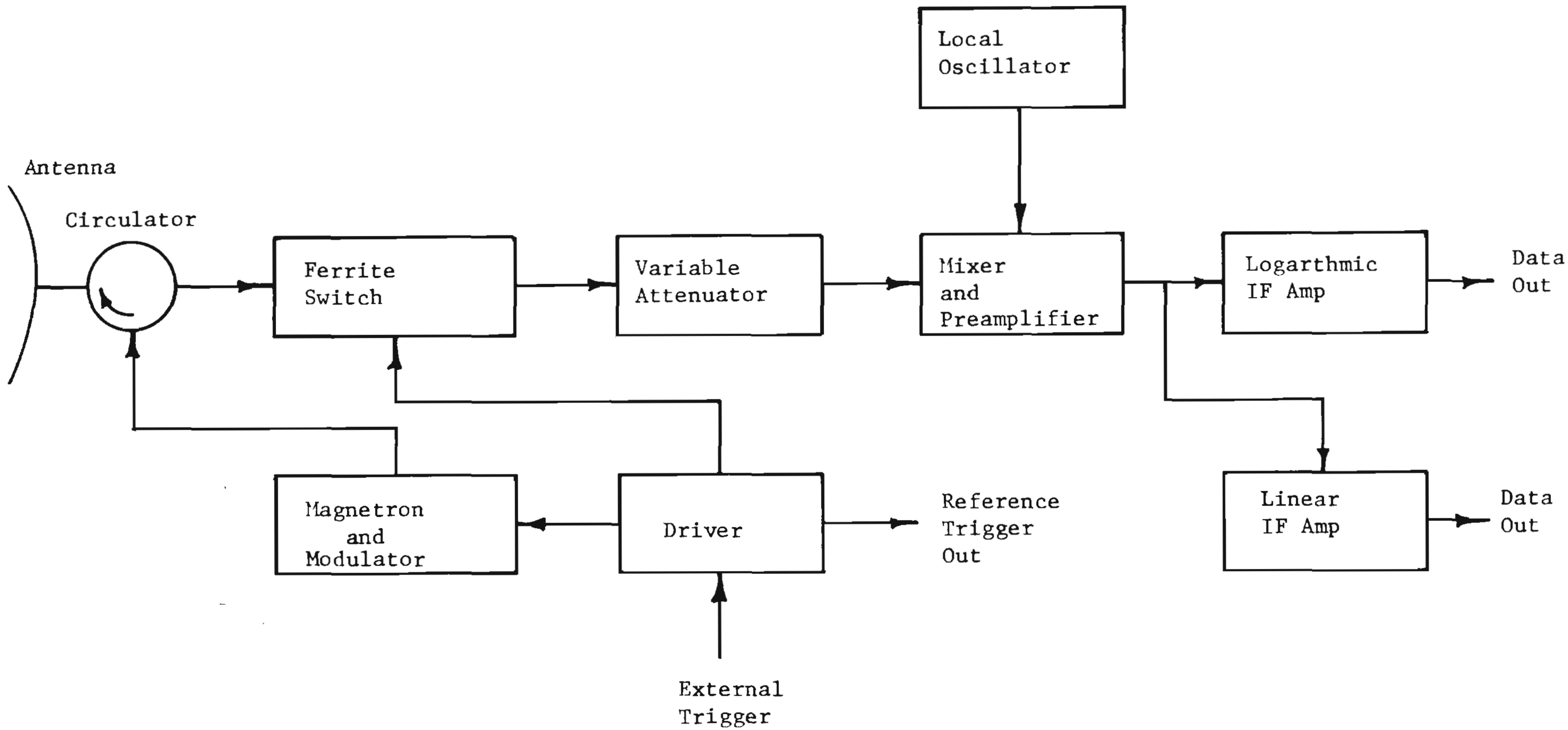


Figure 3. Simplified block diagram of EES 95 GHz radar used during OWEX.

B. Average-Value Data Acquisition System

A number of different types of data were recorded during the course of the experiment. The first and principal data recorded were one second averages of the sampled radar return from sea clutter. These averages were obtained for twenty range gates for each radar video signal sampled, and the video signal was obtained from linear receivers. At the same time, measures of wind speed and direction, and of wave height were also recorded. The radar data were normally further smoothed and used to examine the coupling of internal waves to the average value of radar sea clutter.

A range interval consisting of 20 contiguous 50-nsec range intervals was sampled using samplers each having a gate 50 nsec in width. If this were implemented in straightforward fashion, i.e., using a separate sample and hold (boxcar) circuit for each interval, eighty separate boxcar circuits would be required in order to take data for each of the four video signals simultaneously. The fact that the actual required data rate was much slower than the system prf permitted the time-shared use of the boxcar circuits, thus reducing the number to be fabricated, maintained, and calibrated.

The time-shared use of the boxcar circuits was accomplished in the following manner. For simplicity, consider only one channel (frequency); four contiguous range rates of 50 ns were provided, and this set was stepped (as a group) in range, in synchronization with the system prf, to obtain samples over the desired range interval. This procedure was then repeated. Two pulses were sampled per range position, but only the second was digitized and recorded on tape; the first "dummy sample" was to eliminate any possible settling problems or contamination of adjacent samples. While this procedure did reduce the effective sample rate below the system prf, the resulting sample rate should be adequate for average-value data; with a prf of 1500 pps, 5 discrete range positions for each group of four gates, and one "dummy" pulse to allow any switching transients to die down, the effective sample rate was still 150 per second.

The sampled data were multiplexed through a single A/D converter and stored into memory. Along with these samples were stored time at one-half second intervals, wave height data taken at 1/10 second intervals, and anemometer data. The anemometer data consisted of two inclinometers sampled at 1/10 second intervals, and wind speed, direction (relative) and compass bearing which were sampled at 0.5 second intervals. Occasionally during the course of the experiment, different signals were injected into these connectors, but the sample rates were unchanged.

All of these data were interfaced through a data break interface into the computer memory. The memory address counter and the sequence counter were all hardwired on the interface board in order to maximize the data rate through the interface. Also hardwired through the interface was the master time information, but the actual timekeeping function was carried out in software. The software looked for the change in master time which occurred on the second, and completely updated the time every 4096 half-seconds.

The data were organized into records, blocks and files when they were written on the tape. A single experiment run consisted of a single file containing a number of blocks and each block contained a number of records. End-of-file and end-of-block marks were standard hardware marks; all information was written at 800 bpi on 7-track, odd-parity NRZI industry compatable 1/2-inch magnetic tape (2400-ft rolls). A 12-bit word was used, so each word occupied two tracks on the tape. Averaging was performed within the computer itself, so that a 1-second average was recorded on the tape; a standard record contained 80 smoothed data values, 20 inclinometer values, ten wave height values, two values of wind speed, relative direction, compass heading, and one time entry. Twelve of these standard records were contained within a block; a representative file, block, and record is shown in Figure 4. The detailed record structure is shown in Table II. In Table II the "data sets" refer to the video signal being sampled at each of the

BEGINNING OF FILE

Standard Record

- Run ID
- 80 Data Values
- 20 Inclinometer Values
- 10 Waveheight Values
- 4 Wind Speed
- 4 Wind Direction
- 2 Compass Heading
- 2 Time of Day

.
.
.

11 more
records

.
.
.

End of Block

.
.
.

Additional Blocks

.
.
.

End of Last Normal Block

END OF FILE

Figure 4. Typical file structure for radar data.

TABLE II

Record Structure - See Text for Details

WORD NUMBER	ITEM	WORD NUMBER	ITEM
1	RUN IDENTIFICATION WORD	31	DATA SET 2 WORD 8
2	DATA SET 1 WORD 1	32	DATA SET 3 WORD 8
3	DATA SET 2 WORD 1	33	DATA SET 4 WORD 8
4	DATA SET 3 WORD 1	34	DATA SET 1 WORD 9
5	DATA SET 4 WORD 1	35	DATA SET 2 WORD 9
6	DATA SET 1 WORD 2	36	DATA SET 3 WORD 9
7	DATA SET 2 WORD 2	37	DATA SET 4 WORD 9
8	DATA SET 3 WORD 2	38	DATA SET 1 WORD 10
9	DATA SET 4 WORD 2	39	DATA SET 2 WORD 10
10	DATA SET 1 WORD 3	40	DATA SET 3 WORD 10
11	DATA SET 2 WORD 3	41	DATA SET 4 WORD 10
12	DATA SET 3 WORD 3	42	DATA SET 1 WORD 11
13	DATA SET 4 WORD 3	43	DATA SET 2 WORD 11
14	DATA SET 1 WORD 4	44	DATA SET 3 WORD 11
15	DATA SET 2 WORD 4	45	DATA SET 4 WORD 11
16	DATA SET 3 WORD 4	46	DATA SET 1 WORD 12
17	DATA SET 4 WORD 4	47	DATA SET 2 WORD 12
18	DATA SET 1 WORD 5	48	DATA SET 3 WORD 12
19	DATA SET 2 WORD 5	49	DATA SET 4 WORD 12
20	DATA SET 3 WORD 5	50	DATA SET 1 WORD 13
21	DATA SET 4 WORD 5	51	DATA SET 2 WORD 13
22	Data Set 1 Word 6	52	DATA SET 3 WORD 13
23	DATA SET 2 WORD 6	53	DATA SET 1 WORD 14
24	DATA SET 3 WORD 6	54	DATA SET 1 WORD 14
25	DATA SET 4 WORD 6	55	DATA SET 2 WORD 14
26	DATA SET 1 WORD 7	56	DATA SET 3 WORD 14
27	DATA SET 2 WORD 7	57	DATA SET 4 WORD 14
28	DATA SET 3 WORD 7	58	DATA SET 1 WORD 15
29	DATA SET 4 WORD 7	59	DATA SET 2 WORD 15
30	DATA SET 1 WORD 8	60	DATA SET 3 WORD 15

(Continued on Next Page)

Table II (continued)

WORD NUMBER	ITEM	WORD NUMBER	ITEM
61	DATA SET 4 WORD 15	92	INCLINOMETER 2 WORD 1 (input 17)
62	DATA SET 1 WORD 16	93	INCLINOMETER 2 WORD 2
63	DATA SET 2 WORD 16	94	INCLINOMETER 2 WORD 3
64	DATA SET 3 WORD 16	95	INCLINOMETER 2 WORD 4
65	DATA SET 4 WORD 16	96	INCLINOMETER 2 WORD 5
66	DATA SET 1 WORD 17	97	INCLINOMETER 2 WORD 6
67	DATA SET 2 WORD 17	98	INCLINOMETER 2 WORD 7
68	DATA SET 3 WORD 17	99	INCLINOMETER 2 WORD 8
69	DATA SET 4 WORD 17	100	INCLINOMETER 2 WORD 9
70	DATA SET 1 WORD 18	101	INCLINOMETER 2 WORD 10
71	DATA SET 2 WORD 18	102	WAVE HEIGHT WORD 1 (input 18)
72	DATA SET 3 WORD 18	103	WAVE HEIGHT WORD 2
73	DATA SET 4 WORD 18	104	WAVE HEIGHT WORD 3
74	DATA SET 1 WORD 19	105	WAVE HEIGHT WORD 4
75	DATA SET 2 WORD 19	106	WAVE HEIGHT WORD 5
76	DATA SET 3 WORD 19	107	WAVE HEIGHT WORD 6
77	DATA SET 4 WORD 19	10	WAVE HEIGHT WORD 7
78	DATA SET 1 WORD 20	109	WAVE HEIGHT WORD 8
79	DATA SET 2 WORD 20	110	WAVE HEIGHT WORD 9
80	DATA SET 3 WORD 20	111	WAVE HEIGHT WORD 10
81	DATA SET 4 WORD 20	112	WIND SPEED 1 WORD 1 (input 19)
82	INCLINOMETER 1 WORD 1	113	WIND SPEED 1 WORD 2
	(input 16)	114	WIND SPEED 2 WORD 1 (input 20)
83	INCLINOMETER 1 WORD 2	115	WIND SPEED 2 Word 2
84	INCLINOMETER 1 WORD 3	116	WIND DIRECTION 1 WORD 1 (input 21)
85	INCLINOMETER 1 WORD 4	117	WIND DIRECTION 1 WORD 2
86	INCLINOMETER 1 WORD 5	118	WIND DIRECTION 2 WORD 1 (input 22)
87	INCLINOMETER 1 WORD 6	119	WIND DIRECTION 2 WORD 2
88	INCLINOMETER 1 WORD 7	120	COMPASS AZIMUTH WORD 1 (input 23)
89	INCLINOMETER 1 WORD 9	121	COMPASS AZIMUTH WORD 2
90	INCLINOMETER 1 WORD 9	122	TIME OF DAY WORD 1
91	INCLINOMETER 1 WORD 10	123	TIME OF DAY WORD 2

four inputs, and the "word" refers to the range gate, going from the closest (word 1) to the farthest (word 20). In the case of the environmental data, the words refer to the various time samples. The assignment of names to the various environmental inputs represents the originally intended assignment of inputs; in practice, the inputs were connected to various sensors during the experiment, depending on the available operating sensors and the radar look direction. The time-of-day word is composite (a 24-bit word consisting of two 12-bit segments); the first 6 bits are for the day of the month, while the last 18 bits are a binary word giving the number of half-seconds since the preceeding midnight.

A useful feature of the system was the ability to play back any selected input while data were being recorded, a feature often used during the experiment. Parity error recovery features were also included; these are discussed in more detail in Section IV.

Data blocks overlap each other by 50%; therefore, two records/second were written. Tape consumption was such that a single roll would last longer than 12 hours; this exceeded the length of a normal data run.

C. Pulse-by-Pulse Data Acquisition Equipment

In order to investigate the statistics of the process from which the average-value data of the previous section were derived, pulse-by-pulse (unsmoothed) data from the sea surface were recorded. In order to preserve the full range of fluctuation of the sea return (which may be as large as 50-70 dB), the logarithmic IF output was sampled.

The data acquisition system consisted of, in addition to the radar and the logarithmic IF amplifier, a sample-and-hold circuit and a precision FM analog tape recorder. The sample-and-hold circuit sampled a given video output at a single range and stretched the return for a complete interpulse period. The resulting analog signal was then recorded on the analog FM tape recorder.

Typically, four separate returns were sampled simultaneously at the pulse repetition frequency and recorded on the tape. Also recorded were voice annotation, a time code, and a synchronizing pulse (used in the subsequent digitizing process).

In addition to radar data, calibration signals were also recorded on the tape. This information was then used to generate a calibrated data tape, as discussed in the following section.

III. DATA VERIFICATION AND CALIBRATION PROCEDURES

An integral portion of these OWEX tests was the data verification and calibration procedures used. Three principal types of data were acquired during the course of this experiment: average-value radar data, environmental data, and pulse-by-pulse radar data. Each type of data had its own pecularities and calibration/verification procedures, and is discussed separately in the following paragraphs.

A. Average-Value Radar Data

There are two important features of the average-value radar data: amplitude information and range information. Due to the large amount of data (80 range gates being recorded simultaneously) the verification and calibration process was rather involved. A major means of presenting the data was the so-called "raster plot" which, on a single graph, represented amplitude as a function of time for several different range gates. These plots were used extensively during the data verification process.

Verification of the data acquisition system used to record the average-value radar data involved (after a careful review of the computer program and data-acquisition equipment), first, verification that the correct input went to the correct location in the tape record, and, second, that there was no coupling or contamination between the range gates.

The first test involved injecting a dc voltage sequentially into the input of each sampler. Since each sampler is time-multiplexed, the signal should appear in five positions simultaneously. A raster plot of a portion of the results of one such experiment is given in Figure 5, showing the signal appearing in the correct location with no visible cross-coupling or contamination.

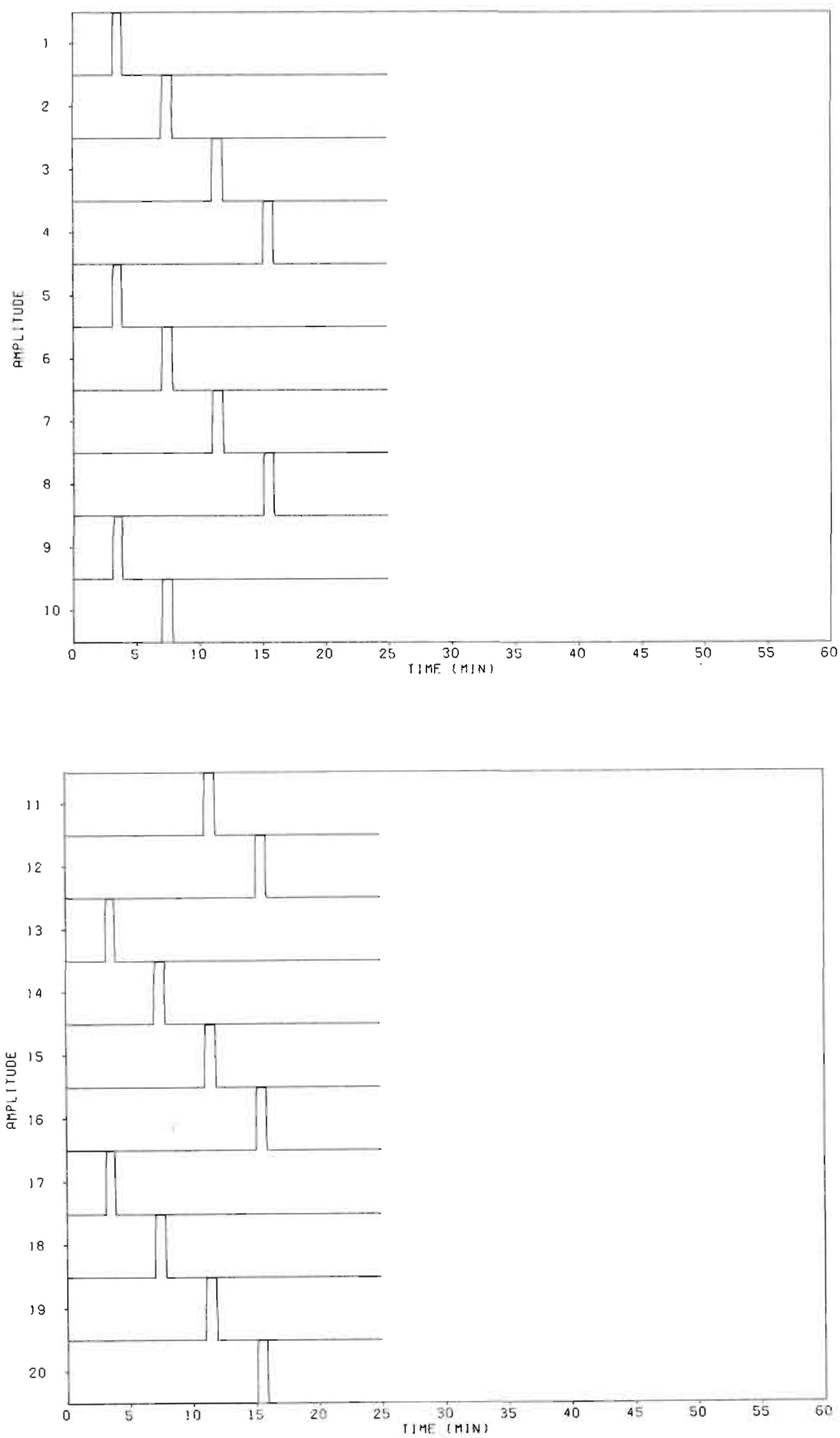


Figure 5. Raster plot resulting from sequentially injecting a dc voltage into sampler inputs. See text for details.

The second test involved injecting a 50-nsec pulse into one sampler input and monitoring the other samplers for contamination. This was done for signals both present and absent in the other samplers; no anomalous behavior was detected.

The third test is the most comprehensive, and was performed several times during and after the field operations. The experiment involved, first, passing a signal sequentially through the range gates, and, second, placing a known signal in a number of gates and varying the signal over the system dynamic range. In order to perform this experiment, an rf signal generator was used to generate a test signal; this signal was approximately 0.2-μsec wide and its delay could be varied. This signal was injected into the front of the receiver, thus exercising the entire data-acquisition system.

A typical test sequence for one of these data channels was as follows. Starting from a range greater than gate 20, the test signal delay was decreased, the test signal traversing the range gates from gate 20 to gate 1. Next, the procedure was reversed and the test signal delay increased. Finally, the test signal was placed near the center of the gates and stepped from saturation to minimum signal.

A representative raster plot from IF amplifer 3 produced from data generated during such a test (performed on 9/10/74) is shown in Figure 6. Correct operation is indicated by: (1) the fact that the signal sequentially passes through the range gates in both directions with no cross-contamination or undesired coupling; (2) there is no contamination of one IF by another IF input, i.e., the inputs are isolated; and (3) the amplitude steps are visible.

Calibration of these amplitude variations was a somewhat complex procedure, since it involved the transfer function of the IF amplifier, the sampler, the computer buffer amplifier, the multiplier, and the A/D converter. The transfer function of the IF amplifier is nonlinear, and was carefully measured; the remainder of the system was linear and could be lumped together as a single calibration.

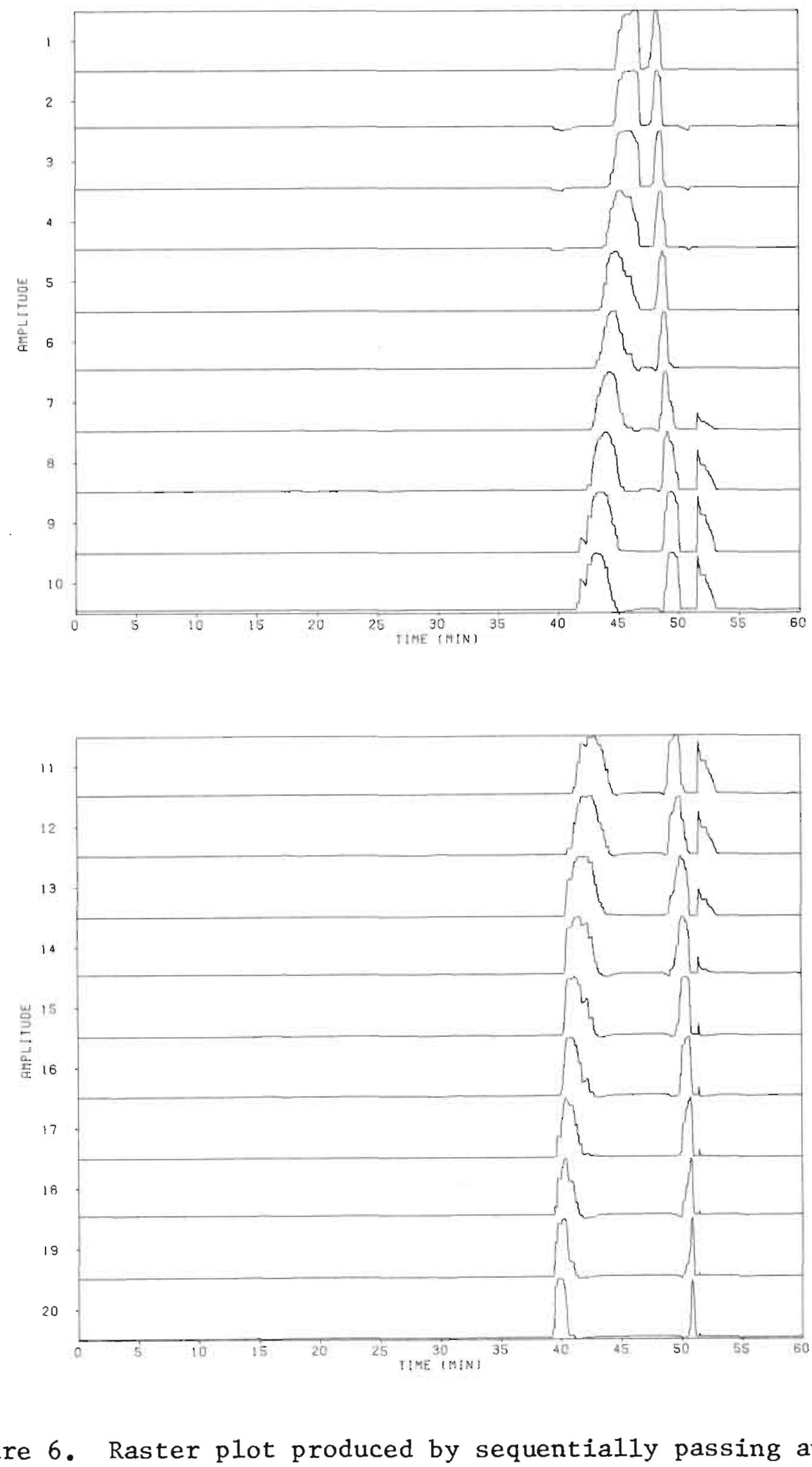


Figure 6. Raster plot produced by sequentially passing an rf test signal through the range gates. See text for details.

The IF amplifier could be considered to be a nonlinear amplifier and detector, preceded by an attenuator whose attenuation was controlled by the STC voltage. A plot of the transfer function of the receiver is given in Figure 7, and the data are tabulated in Table III. Note that the output is given as a fraction of the total output voltage swing. This essentially normalizes out the remaining gains of the system, requiring only a knowledge of the digital word corresponding to the maximum and minimum voltage excursions to complete the calibration. These values varied with system adjustments; a table of representative values is given as Table IV. Note that one of the amplifiers in the chain is an inverting amplifier, so that the maximum voltage output corresponds to the most negative digital values, etc.

The attenuation of the STC attenuator was calibrated as a function of voltage, and this relationship is summarized in Figure 8.

In spite of all of these checks, anomalies were detected in some of the data. These are discussed in more detail in Section IV.

The calibration of the range information involved two separate factors: first, the range to the first range gate, and, second, the spacing of the twenty range gates.

Careful measurements throughout and after the measurement program indicated the spacing remained at 50 nsec within less than 10 nsec for all the gates. The range to the first range gate was less constant and varied from day to day. This information was recorded photographically and was calibrated using a surveyed range at EES (to compensate for receiver delays). This information was then transformed into tower coordinates (referenced to the tower center), taking into account slant vs ground range, antenna location, and look direction. The results are summarized in Table V.

B. Environmental Data

The verification and calibration of the environmental data involve two different tests; the first to determine that there is no cross-contamination of data, and the second to determine the sensitivity of each input.

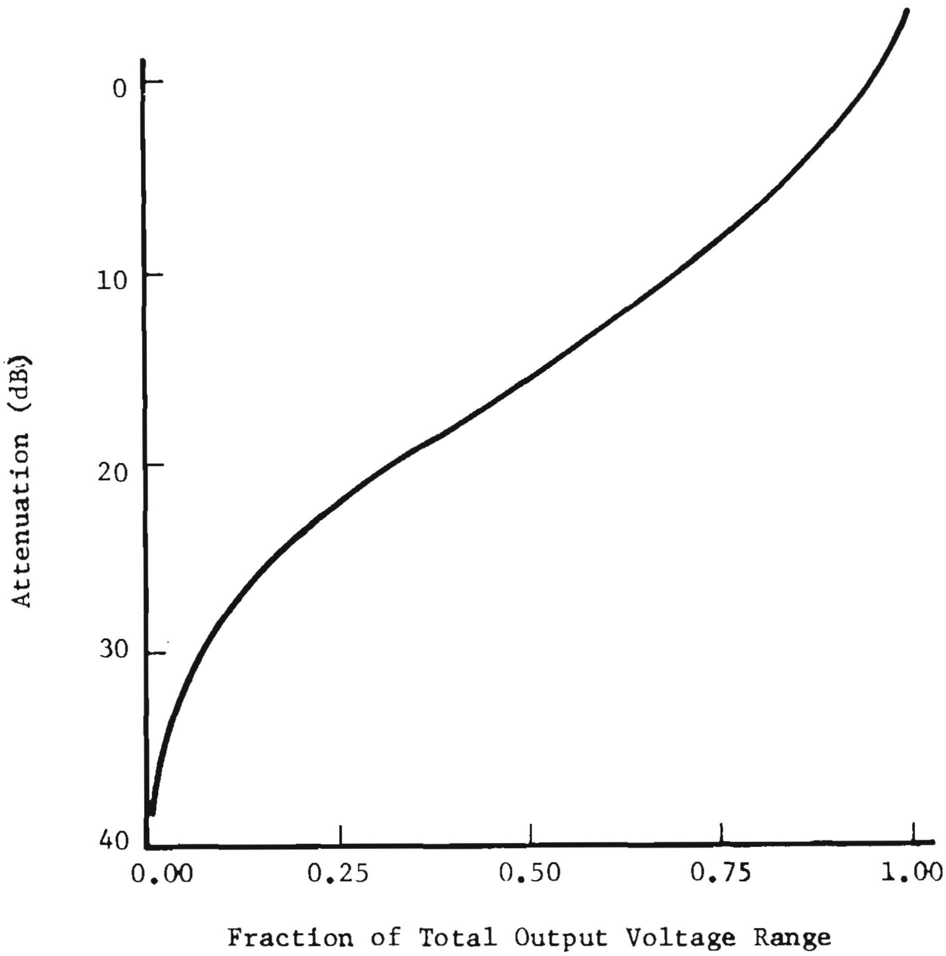


Figure 7. Composite transfer function for the linear IF amplifiers.

TABLE III

Composite Transfer Function -
Linear IF's
(All Four the Same Within 3%)

Attenuation (dB)	Fraction of Total Output Voltage Excursion
0	0.96
4	0.86
8	0.75
12	0.63
16	0.50
20	0.33
24	0.20
28	0.11
32	0.04
36	0.01
40	0.0

TABLE IV

Representative Maximum/Minimum Values for
Average-Value Radar Data.

Range Gate Number	DATA SET			
	1	2	3	4
1, 5, 9, 13, 17	1430/-1056	1089/-1141	1329/-1104	1176/-1262
2, 6, 10, 14, 18	1376/-1190	1097/-860	1196/-1057	1204/-1460
3, 7, 11, 15, 19	1393/-680	1432/-661	1316/-560	1240/-740
4, 8, 12, 16, 20	1220/-693	1217/-597	1217/-243	1104/-961

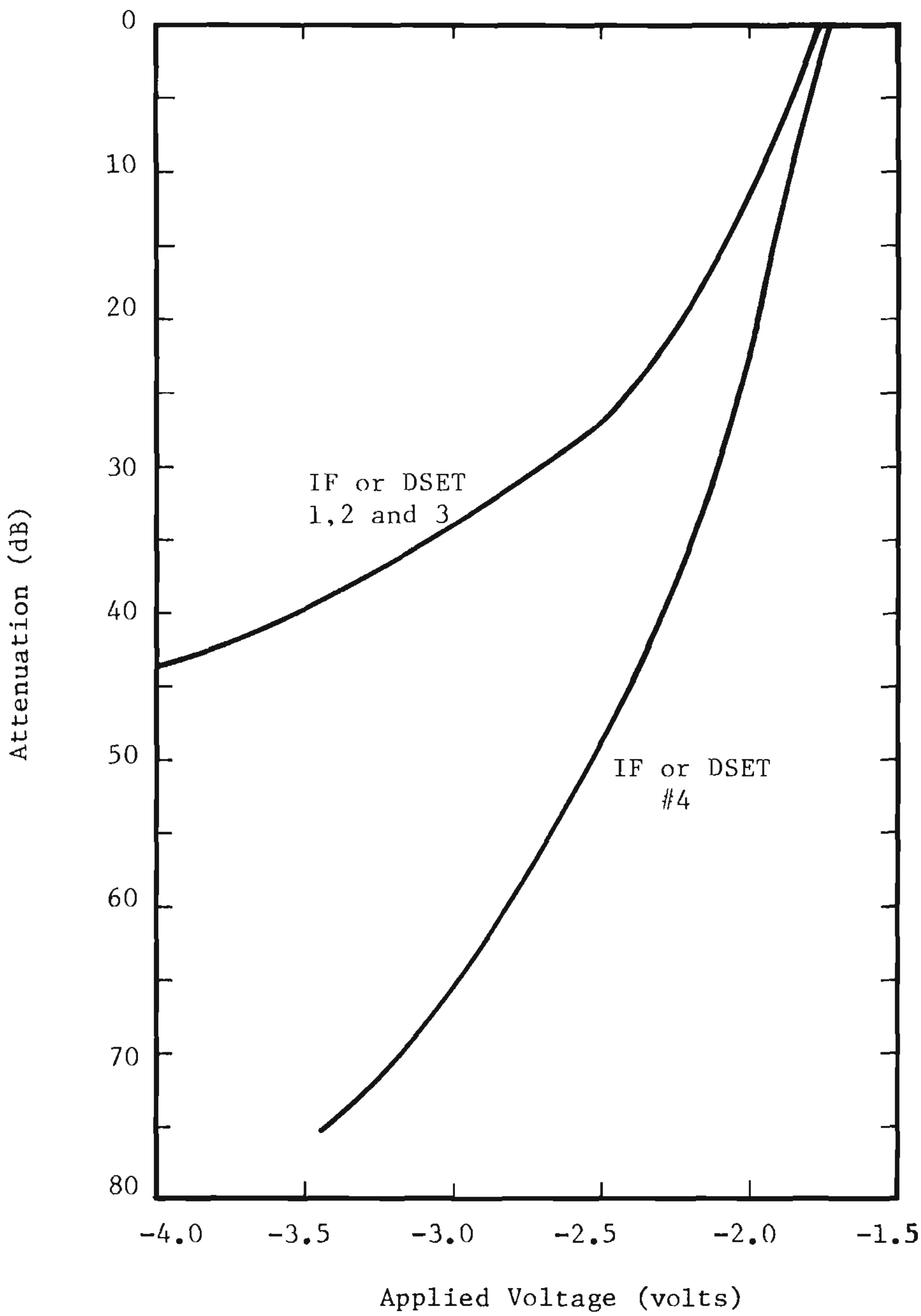


Figure 8. STC attenuation as a function of the applied voltage. The applied voltage is the sum of the constant gain voltage and the range-varying STC wave form voltage.

TABLE V

First Range Gate Location (Meters) Referenced to the Center of the Tower

Tape Roll	Date	IF or Data Set			
		1	2	3	4
13	8/29/74	106	-	-	-
14	8/30/74	106	-	-	-
15	9/3/74	97	-	-	-
16	9/4/74	97	-	-	-
17	9/5/74	101	-	-	-
18	9/6/74	99	-	-	-
20	9/9/74	106	-	-	-
21	9/10/74	96	96	99	100
22	9/11/74	96	96	99	100
23 (After 1353)	9/12/74	107	107	104	105
23 (Before 1353)	9/12/74	114	114	113	108
24	9/13/74	102	102	103	102
25 (Before 1215)	9/16/74	96	96	96	96
25 (After 1215)	9/16/74	104	104	100	100
26	9/17/74	92	92	87	87
27	9/17/74	107	107	103	103
29	9/18/74	101	101	111	106
30	9/19/74	100	108	108	105
31	9/20/74	92	96	96	84
33,32	9/21/74	92	102	102	93
35,34	9/22/74	89	105	105	90
36	9/23/74	106	106	105	105
37	9/24/74	74	74	85	83
38	9/25/74	99	-	-	-

The first test was to ensure that the correct data inputs are being transferred to the proper location on the tape. In order to do this, a triangular wave generator (which has some dc offset) was sequentially connected to each of the environmental data inputs, while all the other inputs were terminated with 220-ohm resistors (termination of unused inputs is necessary, since an open-circuited input rises to its maximum value, producing a digital number of 2047 on the tape). A raster plot of the resulting data is shown as Figure 9. No attempt was made to control carefully the amplitudes of the signals which were applied; however, it is evident that Channels 2 and 3 have gains considerably in excess of Channels 1 and 4 through 8 (this is normal behavior). The large transients which occur at the beginning and end of each of these runs are associated with connection and disconnection of inputs and terminations. During reconnection, the inputs are open-circuited and the apparent input voltage rises to a large positive value during that interval. The transient which occured at the end of the run on No. 2 appearing on Channel 1 is associated with an operator error occurring at that time; the termination of Input 1 was inadvertently removed during the transfer to Input 3. Careful examination of this raster plot reveals no apparent difficulties with cross-contamination of data or with the identification of data by its location on the digital tape.

The second test was to determine the transfer function of the input analog signal to the digital word which is written on the digital tape. In order to perform this calibration, a variable dc power supply was connected to both a digital voltmeter and to the various inputs to the computer. The input voltage was then changed through known values and the resultant signal was recorded on tape; these values were then displayed. The resulting calibrations were summarized in Table VI.

The gains of the various amplifiers were changed at various times during the experiment, and this is reflected in the table. Note that these data are not inverted, i.e., the most positive input produces the most positive digital number.

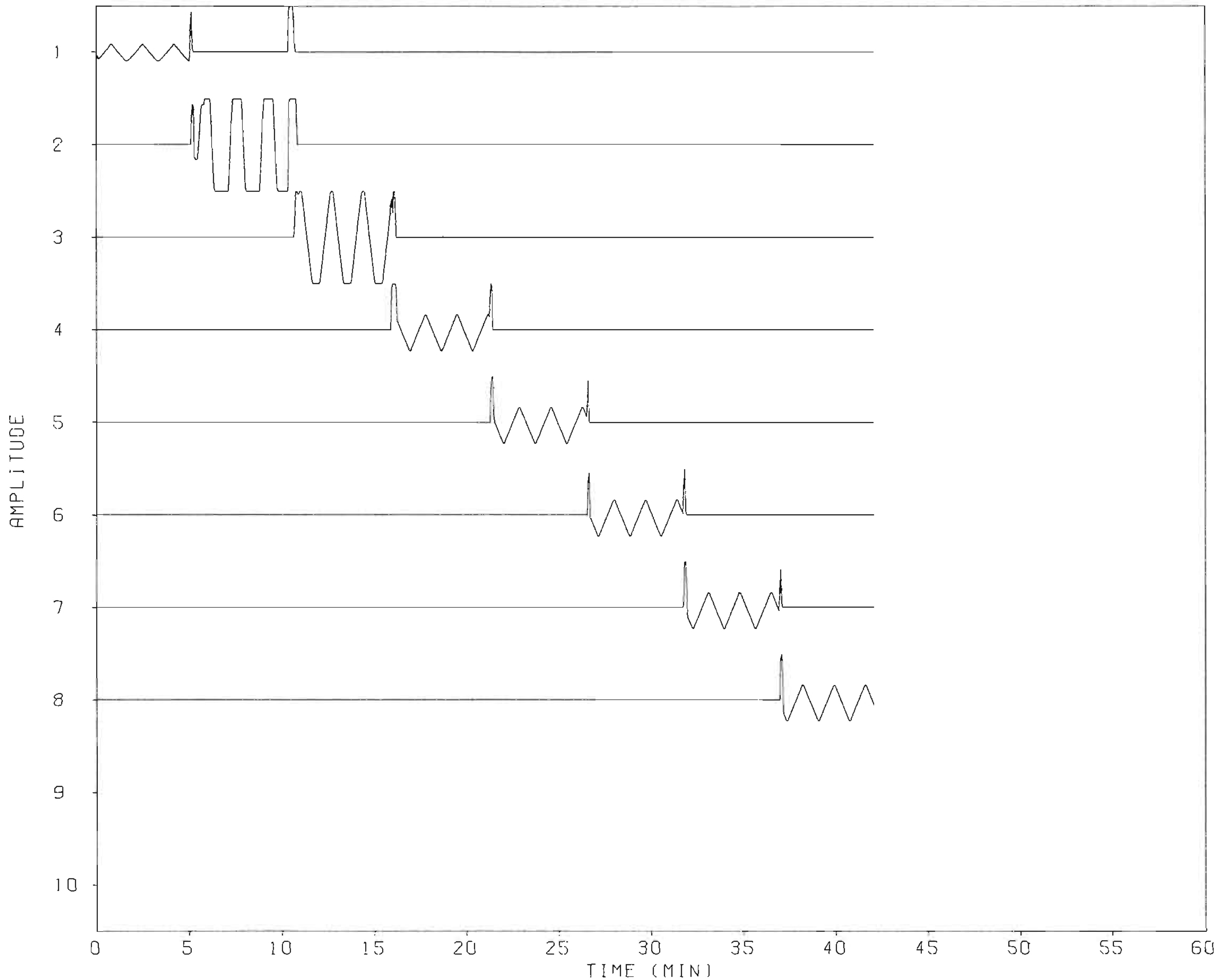


Figure 9. Raster plot of environmental data recording test. See text for details.

TABLE VI

Sensitivity of Environmental Inputs

Input No.	Sensitivity (/volt) ± 2 Counts
16	200
17	200 thru 9/17, 1920 after 9/17
18	200 thru 8/20, 721 after 8/20
19	200
20	200
21	200
22	200
23	200

C. Pulse-by-Pulse Data

The equipment and procedures used to acquire the pulse-by-pulse data have been verified on numerous other Georgia Tech programs. Verification for OWEX was limited to examination of the data being recorded on tape, and setup and observation of sampler operations.

The data were recorded on an analog FM tape and returned to Georgia Tech for digitizing and calibration. The same data acquisition system used during the field operation for average-value data was used to digitize the information previously recorded on tape (using different software). The recorded clock signals were used to determine the point at which to convert the data. Printouts of the resulting records were used to verify the process.

The data format was a file consisting of a number of 1536-12 bit word blocks. This block consisted of 384 samples of each of four inputs in the order input 1, input 2, input 3, input 4, input 1,....

Calibration of these data were accomplished by use of recorded calibration signals. A RF signal generator was used to inject known signals into the receiver input. The mode (most probable value) of the resulting recorded signal was defined to be the value for that signal. The resulting set of data points were used to generate a cubic least mean square fit calibration curve relating digital values to received power in units of dBm x 10. This calibration function was then used to generate a new digital tape containing a pulse-by-pulse record of the received power in dBm x 10.

IV. REPRESENTATIVE DATA

Using the equipment discussed in Section II and the calibration procedures discussed in Section III, a considerable amount of average-value radar data, environmental data, and pulse-by-pulse data were taken. The characteristics of these data are discussed in some detail in the following paragraphs.

A. Average-Value Radar Data

Average-value radar data were taken throughout the experiment whenever environmental conditions warranted their recording. As discussed earlier, there were provisions for recording only four video signals; these signals were selected from the available set throughout the experiment to maximize the variety of data acquired, but the 9.5 GHz parallel channel was always recorded as a reference or baseline data set. Types of radar data recorded included both parallel-and cross-polarized channels for 9.5, 16.5, and 35 GHz data for both horizontal and vertical polarizations. In addition, it was planned to take horizontal and vertical parallel-polarized data at 95 GHz; unusually broad magnetron spectra (which substantially reduced power in the receiver passband) coupled with lower than expected clutter returns prevented any meaningful data from being taken at this frequency. Reliability of all of the radar and data-acquisition equipment was excellent; at no time was data acquisition prevented due to equipment problems.

Over 200 hours of average-value and environmental data were taken during the OWEX. These data are summarized in Table VII. Environmental and range data were also taken for each run. A representative raster plot of some of these radar data is shown in Figure 10.

The time of day was written on these tapes at half-second intervals. On the first tapes this information was entered incorrectly; this error was partially remedied with a program "patch." On further examination, some tapes were found to have incorrect time during the first portion of the tape, because the time was not updated at the beginning of each file, but only at fixed intervals. After a maximum of 4096 half-seconds, the time was updated, and was correct after that point. After the experiment, the tapes were copied at EES and the correct time written onto these early records.

TABLE VII
Average-Value Radar Data Taken During OWEX

Digital Tape Number	Date	Time	Data Recorded			
			1	2	3	4
2	8/17/74	0926-1800	9.5-VV	16.5-VV	35-VV	16.5-VH
3	8/18/74	1000-1731	9.5-VV	16.5-VV	35-VV	95-VV
4	8/19/74	1007-1441	9.5-VV	16.5-VV	35-VV	16.5-VH
5	8/20/74	0945-1751	9.5-VV	16.5-VV	35-VV	95-HH
5 (dup. no.)	8/21/74	1006-1750	9.5-HH	16.5-HH	35-HH	95-HH
6	8/22/74	0924-1734	9.5-HH	16.5-HH	35-HH	95-HH/16.5-HV
7	8/23/74	0851-1732	9.5-VV	16.5-VV	35-VV	16.5-VH
8	8/26/74	0848-1730	9.5-VV	16.5-VV	35-VV	35-VH
9	8/27/74	0859-1449	9.5-VV	16.5-VV	35-VV	35-VH
11	8/28/74	0958-1730	9.5-VV	16.5-VV	35-VV	35-VH
13	8/29/74	1002-1740	9.5-VV	16.5-VV	35-VV	35-VH
14	8/30/74	1003-1716	9.5-VV	16.5-VV	35-VV	16.5-VH
15	9/3/74	1003-1745	9.5-VV	16.5-VV	35-VV	35-VV
16	9/4/74	1229-1730	9.5-VV	9.5-VH	16.5-VV	35-VV
17	9/5/74	1203-1731	9.5-VV	9.5-VH	16.5-VV	35-VV
18	9/6/74	1114-1535	9.5-VV	9.5-VH	16.5-VV	35-VV
20	9/9/74	1049-1713	9.5-VV	9.5-VH	16.5-VV	35-VV
21	9/10/74	1017-1558	9.5-VV	9.5-VV	16.5-VV	35-VV
22	9/11/74	0945-1403	9.5-VV	9.5-VH	16.5-VV	35-VV
23	9/12/74	0955-1457	9.5-VV	9.5-VH	16.5-VV	35-VV
24	9/13/74	0934-1722	9.5-HH	9.5-HV	16.5-HH	35-HH
25	9/16/74	0938-1643	9.5-VV	9.5-VV	16.5-VV	35-VV
26	9/17/74	1042-1433	9.5-VV	9.5-VH	16.5-VV	35-VV
27	9/17/74	1445-1725	9.5-VV	9.5-VH	16.5-VV	35-VV
29	9/18/74	1244-1741	9.5-VV	9.5-VH	16.5-VV	35-VV
30	9/19/74	1329-1740	9.5-VV	16.5-VV	16.5-VH	35-VV
31	9/20/74	1350-1540	9.5-VV	16.5-VV	16.5-VV	35-VV
32	9/21/74	1124-1850	9.5-VV	16.5-VV	16.5-VH	35-VV
33	9/21/74	1900-2237	9.5-VV	16.5-VV	16.5-VH	35-VV
34	9/21,22/74	2241-0830	9.5-VV	16.5-VV	16.5-VH	35-VV
35	9/22/74	0904-1723	9.5-VV	16.5-VV	16.5-VH	35-VV
36	9/23/74	1424-1740	9.5-VV	9.5-VH	16.5-VV	16.5-VH
37	9/24/74	0909-1751	9.5-VV	9.5-VH	16.5-VV	16.5-VH
38	9/25/74	1117-1708	9.5-VV	9.5-VH	16.5-VV	35-VV

The tape identification numbers were sometimes incorrect during the initial portions of a file due to the same reason that time entries were incorrect, i.e., the information was only updated every 4096 entries. This was not corrected during editing, so that some tapes have the wrong ID number for the initial records. This information is summarized in Table VIII.

The data-acquisition program had a parity error correction feature which inadvertantly introduced some errors into the recorded data. The intended functioning of the parity error recovery feature was as follows: once the read-after-write function detected a parity error, the tape was rewound to the beginning of the block in which the error occurred, an extended interrecord gap written over the block containing the error, and the block then rewritten. Unfortunately, the rewind function was not executed, and so when a parity error was detected, the extended interrecord gap was written and the block rewritten, the first block being only a partial one terminating in a parity error. Since no data were lost, a program was written at Georgia Tech to transfer data to a new tape, correcting the error. A summary of tapes corrected in this manner is given in Table IX.

Another important feature of the average-value radar data was the location of the range gates of the sample-and-hold circuits. As indicated in Section II, the relative spacing of these gates remained approximately constant; but the range to the first gate did, in fact, vary from run-to-run. Part of this variation was due to the fact that a constant radar range results in differing ranges for different look directions, when the range is expressed in tower coordinates, because the antennas are displaced from the reference for the tower coordinates. The remainder of the variation was discussed in Section III, and is apparently associated with variations in the delay between the generation of the transmitter trigger and the actual generation of the transmitted rf pulse. These variations are included in the data presented earlier in Table V.

During the course of the experiment, the antennas were pointed to look at the buoys which supported the environmental measurement equipment. This was done on five different occasions, associated with tape rolls 24, 27, 29, 35, and 37.

TABLE VIII

Tape Run Number Errors (First Blocks Only)

Tape Number	First Blocks Read
5	4
13	12
27	26
29	1040
31	24
33	32

TABLE IX

Tapes with Block Errors and Corrected Tape Numbers

Tape Number	Corrected Tape Number
6	B043
9	B042
11	B044
20	B038
24	B035
30	B021
32	B028
33	B019
34	B016

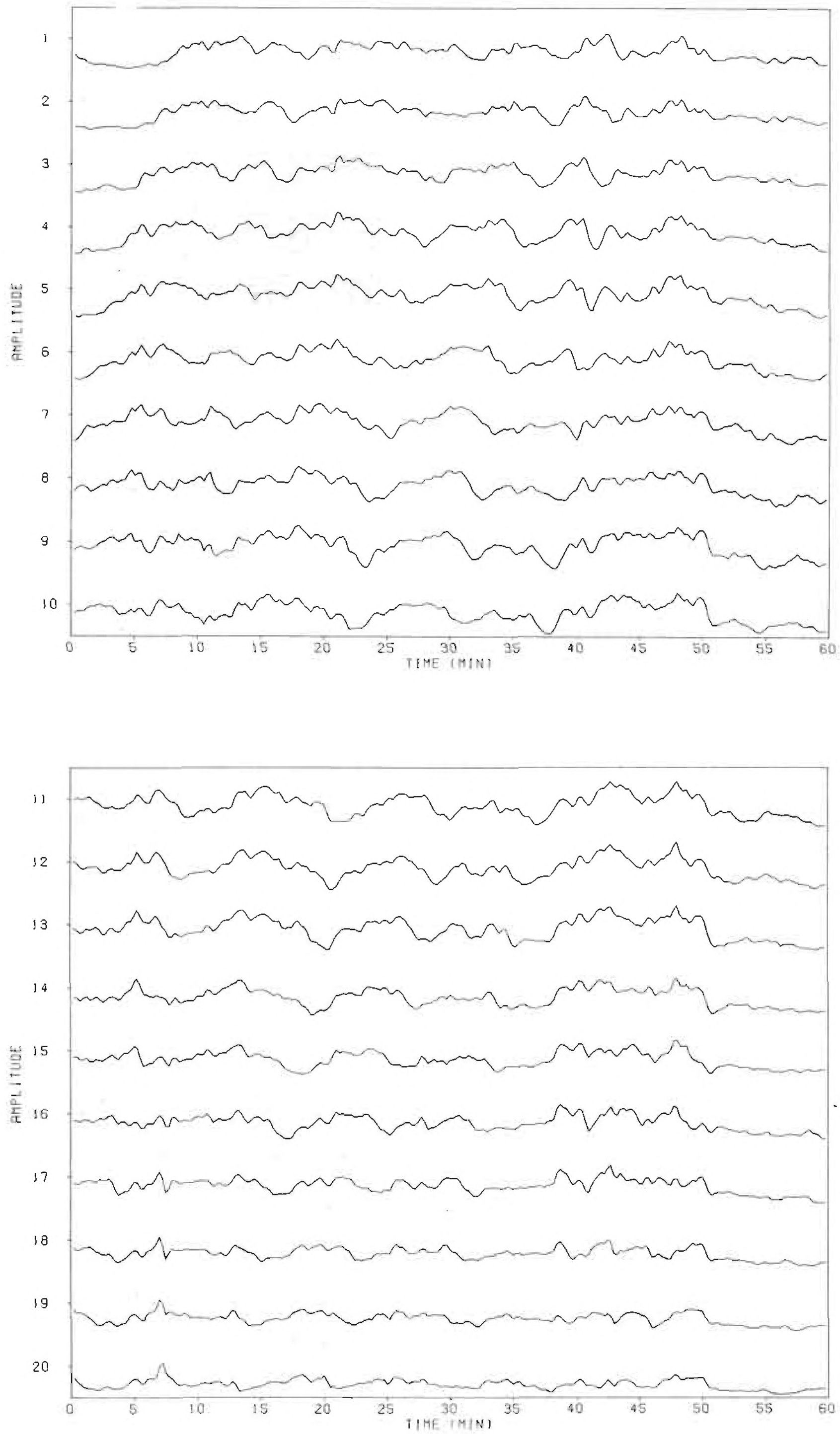


Figure 10. Raster plot of average-value data; one minute smoothing was used.

The expected evidence of the presence of the buoy return was not observed on run 37. The behavior of the data for the remainder of the runs indicated a reasonable agreement in buoy position and expected range gate location for run 27, and poor agreement for runs 24, 29, and 35. Table X summarizes the results of these measurements, showing the anticipated and actual first gates. Note that run 27 shows reasonable agreement, but the others exhibit a substantial difference between the first gate with return and the gate location predicted from the measured first gate position.

The reason for the variance between the anticipated and actual gates containing the return has not been satisfactorily explained. Measurements made since the return of equipment to EES using corner reflectors on a surveyed range have shown good agreement between anticipated and actual results. The only run which was analyzed in detail during the experiment was run number 27, which showed good agreement.

One possible explanation for the differences would be drift in the transmitter firing point. This was examined in some detail in connection with the tables prepared earlier, and while the delay varied from day to day by an appreciable amount, the variation during a single day after a warm-up of 30 minutes was less than one range gate width. Thus, there is offered no explanation for this inconsistency; this is probably the major shortcoming of this experiment, and one which should be remedied if similar tests are to be performed in the future.

The vast majority of the average-value radar data appeared to be well-behaved, exhibiting no anomalies or unexpected behavior. However, there were three features of these data which were worthy of note. First, for data set number two, operations of the second of the four samplers was intermittent; thus, range gates, 2, 6, 10, 14, and 18 are suspect. Usually this data set was either 9.5 GHz cross-channel or 16.5 GHz parallel channel data. The malfunction was rather infrequent, and much of these data are useful, but caution is indicated.

TABLE X.
Correlation of Actual Buoy Position, and Position as Sensed by the Radars

Tape Reel/ Data Set	Look Direction	Distance to Buoy (M)	Distance to First Gate (M)	Anticipated First Buoy Gate	Actual First Buoy Gate
24/1	East	140	102	5	8
24/2	"	"	102	5	8
24/3	"	"	103	5	9
24/4	"	"	102	5	8
27/1	West	136	107	4	5
27/2	"	"	107	4	5
27/3	"	"	103	4½	5
27/4	"	"	103	4½	5
29/1	"	"	101	4½	8
29/2	"	"	101	4½	8
29/3	"	"	111	3½	9
29/4	"	"	106	4	9
35/1	"	"	89	6¼	13
35/2	"	"	105	4	12
35/3	"	"	105	4	13
35/4	"	"	90	6¼	13

The second feature is that for some data, the signal in the close-in range gates was contaminated because the receiver had not fully recovered from the transmitted pulse. The contaminated range gates varied with frequency and with strength of the sea clutter return. RDA maintained an accurate record of the valid gates and should be consulted for accurate determination of range gates containing valid data.

The third feature of the radar data is shown in Figure 11, giving a raster plot of one hour of data from tape reel no. 32. Note that there appears to be a grouping of the range gates into "families" of four, having similarities, but being different from the next group of four in minor details. The reason for this behavior is somewhat puzzling, particularly since it was not evident on all of the data runs, but only for a few isolated cases.

The tests described in Section III argue against a program or data acquisition problem being the culprit. The next most likely cause is contamination or cross-coupling in the samplers themselves; however, tests of sampler operation, both with and without other samplers operating and handling large signals, failed to disclose any cross coupling or contamination. Another likely cause was coupling or distortion of the STC waveform; however, measurements performed both during and after the experiment failed to disclose any waveform aberrations which would account, even partially, for the observed grouping.

The most likely explanation which can be made for this behavior is associated with the saturation behavior of the linear IF amplifiers used during these experiments. The use of linear receivers for average-value data acquisition was dictated by the rather stringent accuracy requirements set forth during experiment planning. Use of a linear IF amplifier results in a system of limited dynamic range. In particular, some care was required to avoid excessive saturation while still having a signal of sufficient amplitude for meaningful data acquisition. Once the IF amplifiers saturate, there is a "stretching" of the received pulse (due to charge-storage in the amplifier transistors, as well as the non-rectangular input pulse shape), which

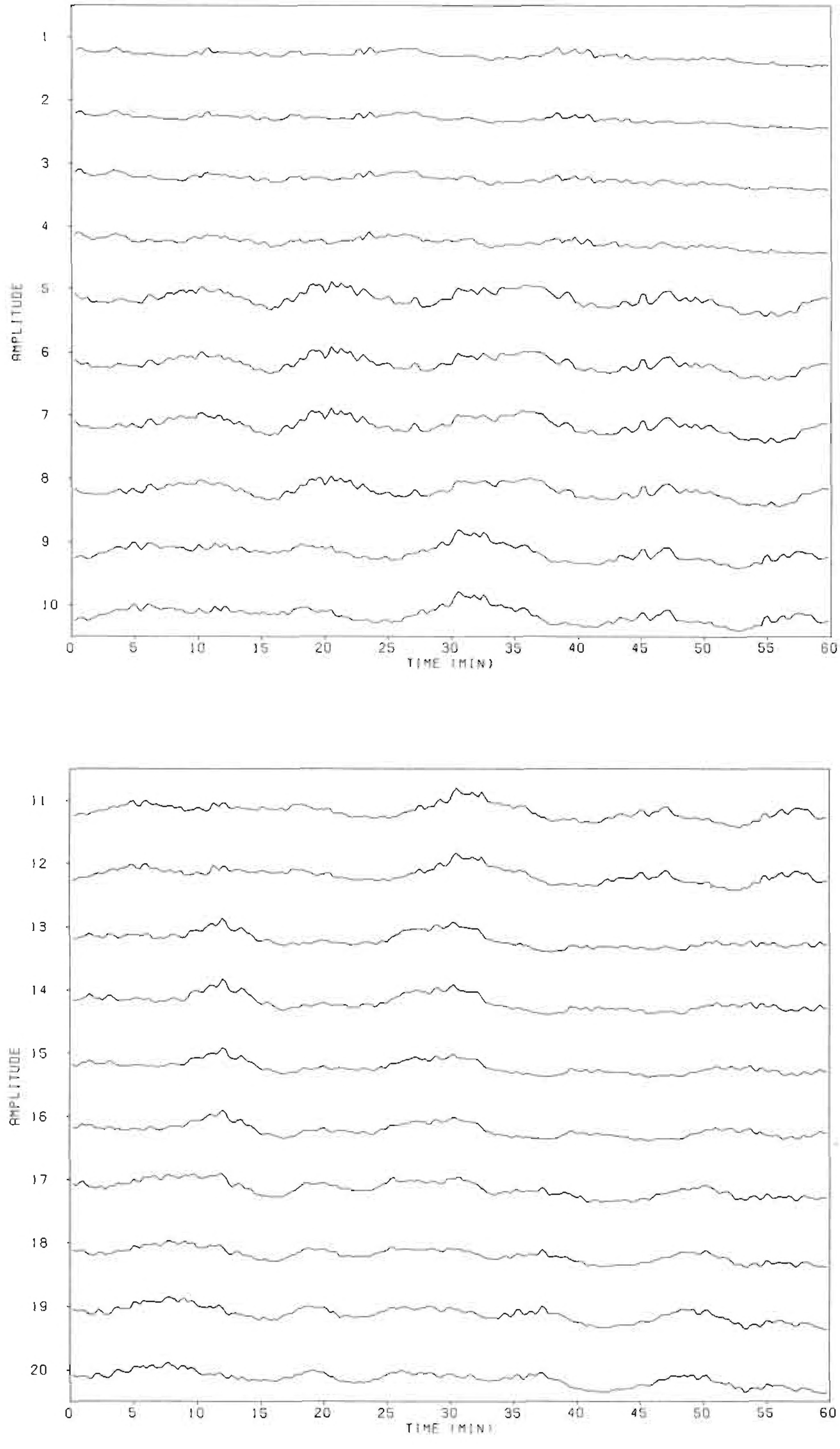


Figure 11. Raster plot of reel 32, showing grouping of gates into groups of four. See test for details.

would have the effect of contaminating the adjacent range gates.

The hypothesis to account for the grouping of fours rests on the saturation behavior of the IF's, on the functioning of the data-acquisition system, and on the behavior of sea clutter itself. Under the right conditions, the sea clutter return is very "spiky," i.e., it contains short-duration, high-amplitude spikes. When this condition exists, a certain amount of saturation of the IF amplifiers is inevitable if meaningful average-value data are to be preserved. This saturation cross contaminates the four samples being taken at a particular time. This does not happen on each received pulse, so there are differences among the elements in a group of four (i.e., they are not identical), but it occurs often enough to impart some similarity. While it would be difficult to conclusively prove this, oscilloscope photographs taken during such runs do indicate that some saturation is evident.

If this is indeed the explanation for this behavior, then no malfunctioning of the system is indicated and the grouping is a manifestation of the system transfer function and the nature of the sea clutter during that particular run.

It is perhaps appropriate to reiterate at this point that EES involvement in the reduction of these data was limited to furnishing raster plots, corrected copies of data tapes, and calibration information to RDA for further analysis.

B. Environmental Data

As mentioned earlier, eight channels of environmental data were recorded along with the average value radar data. As with the average-value radar data, EES performed little analysis of these data, efforts being largely confined to providing tapes, plots, and calibration information to RDA for further analysis.

While originally set-up for specific environmental sensors, the inputs were connected to various sensors, depending upon the look direction and upon which environmental sensors were functioning at the particular time. A representative raster plot of recorded environmental data is given as Figure 12.

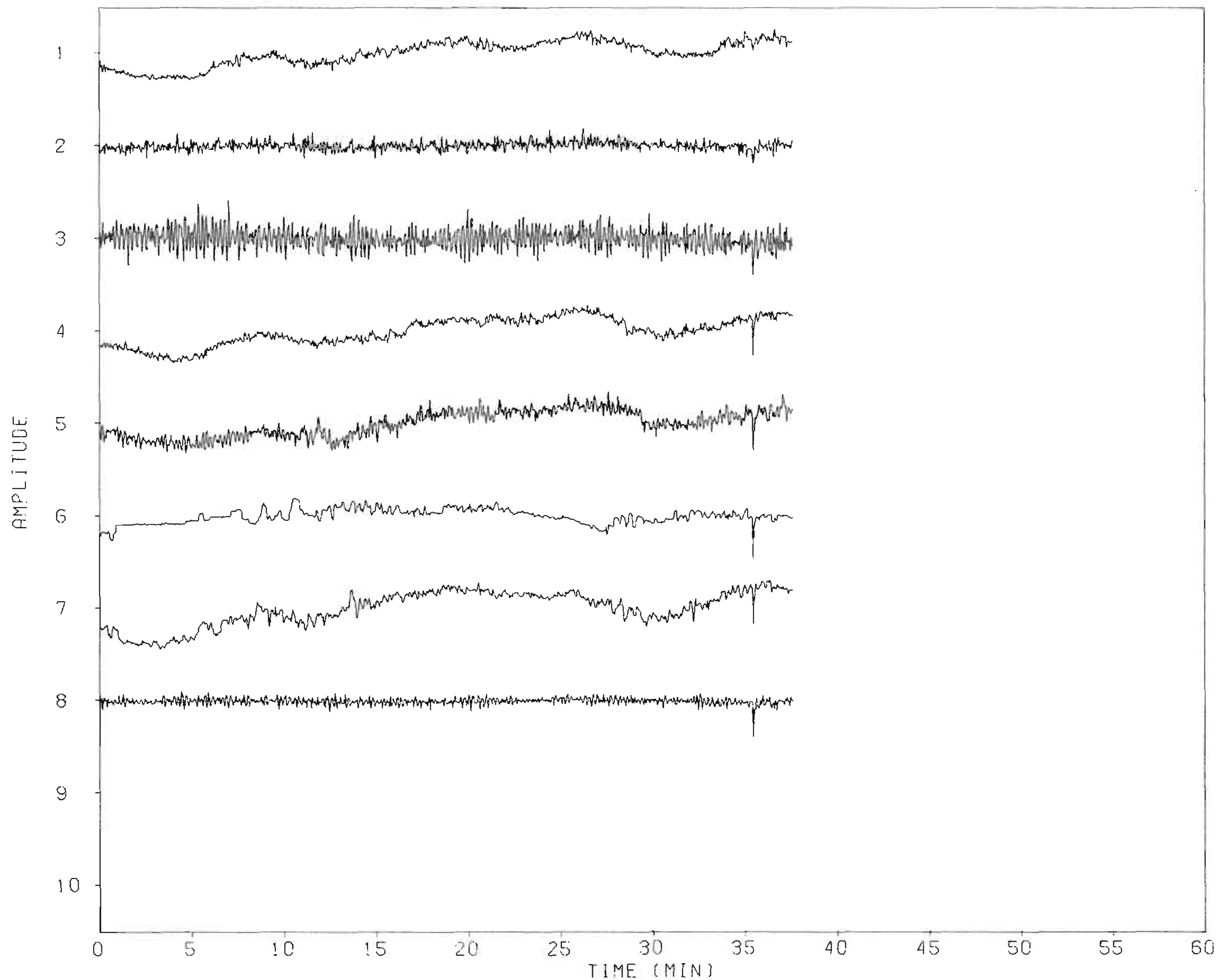


Figure 12. Raster plot of environmental data.

While the verifications outlined in Section III and brief spot checks performed during the course of the experiment indicated no difficulties, some problems were evident once certain of these data were plotted. These problems took the form of excursions added to the data; Figure 13 shows one such set of data which exhibited these characteristics.

Considerable effort was expended in an attempt to determine the cause of these anomalies in the environmental data. The outputs of some of the environmental sensors were carefully examined in order to make sure the actual data exhibited no such excursions; neither tests performed after the operation nor examination of the stripchart recordings made during the experiment revealed any such difficulties. It would appear unlikely that either an open or a short in the input data cable to the computer would cause such difficulties, since an open circuit input results in a large positive value while a short would result in a value close to zero. Numerous tapes (for example Tape 38 file 14) were carefully examined, and in every case the extraneous negative spike was associated with a negative number (usually between -100 and -1000) being written on the tape. Thus, a loose or intermittent connection seems unlikely.

The possibility of a malfunction of the data break interface, the computer software, or the hardware buffers was considered. The tests outlined in Section III make it unlikely that it is an internal error in the computer. There was a hardware failure after return of the system to Georgia Tech; an integrated circuit D-type TTL flip-flop was weak and finally failed. However, if this problem existed during the experiment, data would be placed in the wrong memory address location. This would result in both radar and environmental data being affected, and once an input was corrupted, all higher inputs would also be affected. This was not the case; for example, examination of the first and second hour of tape 25 (See Figure 14) shows several instances where one signal is affected but not the higher numbered inputs. Examination of a number of the tapes (for one example see tape 32, 33 minutes into the run) shows numerous cases where environmental data are affected but radar data are not affected.

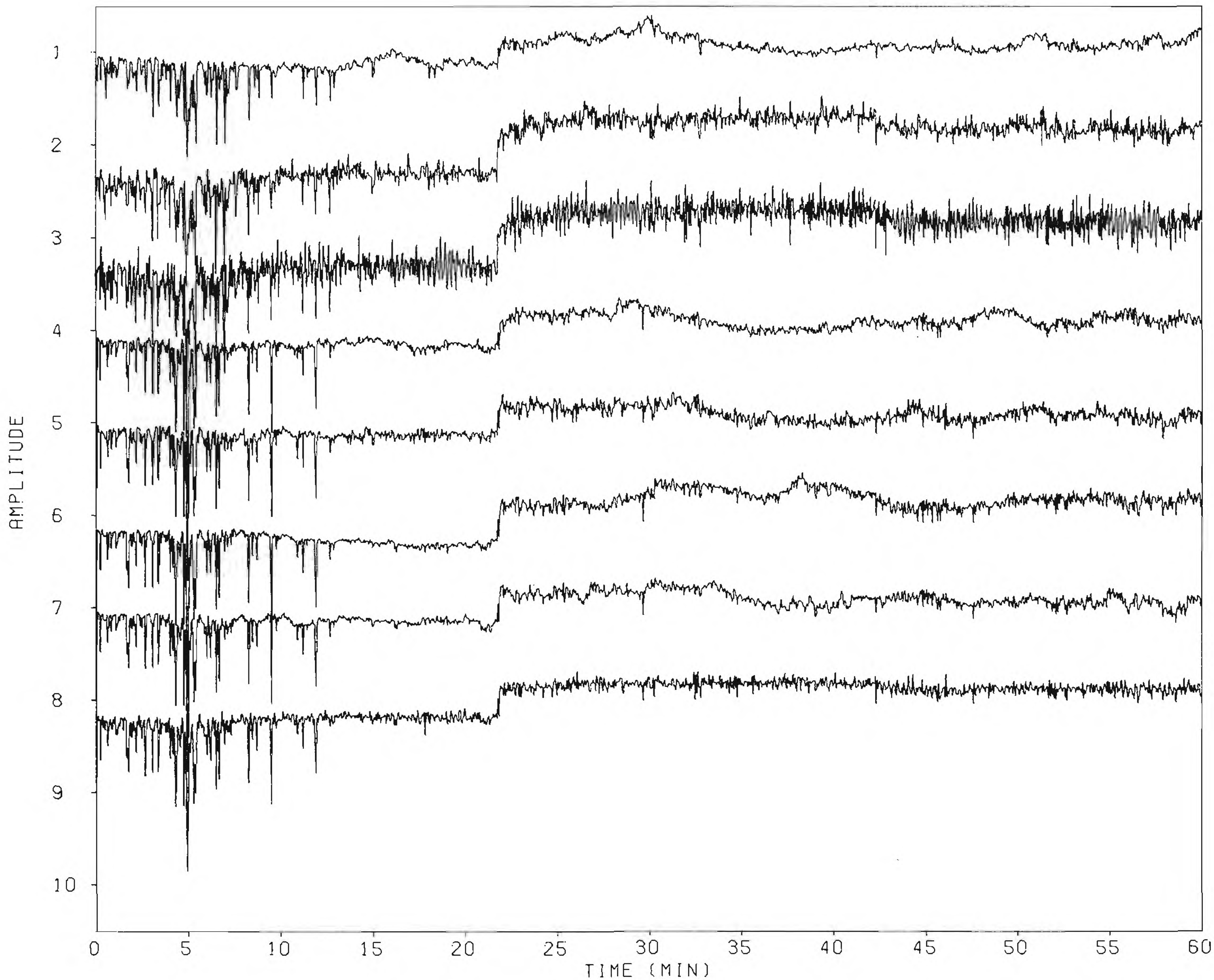


Figure 13. Raster plot of environmental data showing both spike-like an step contaminations of the data. See text for details.

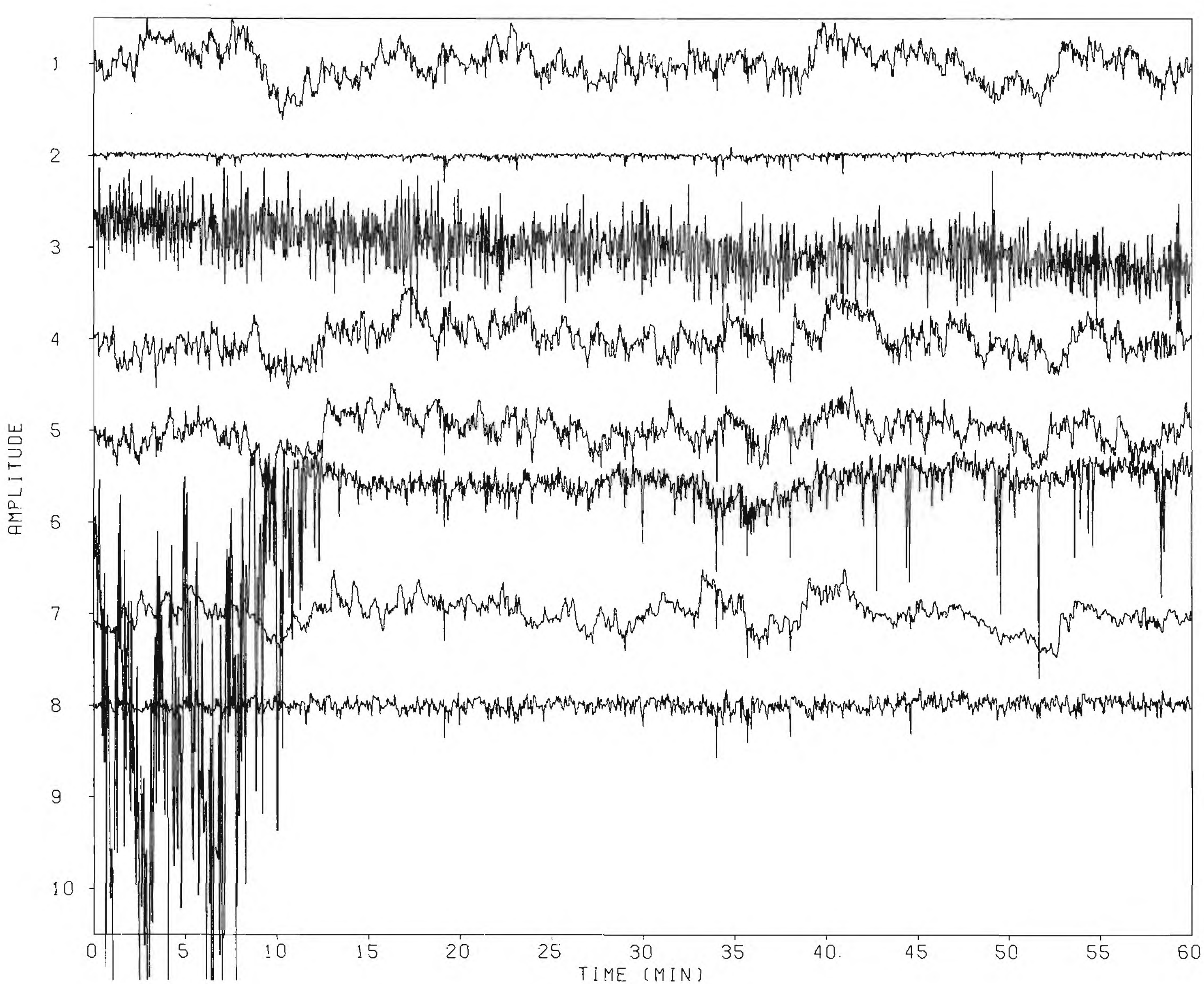


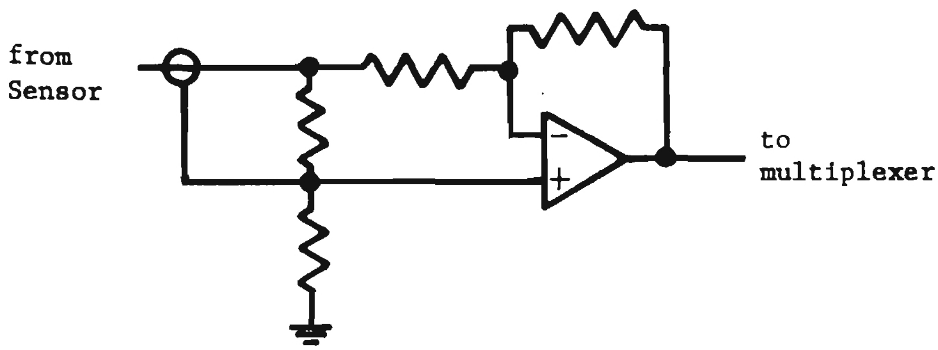
Figure 14. Raster plot of environmental data showing contamination in some channels without corresponding contamination of higher-order channels.

The remaining possibility involves the buffer amplifier circuits. It is possible that oscillation of the buffer amplifiers could produce such difficulties, but exhaustive tests have failed to uncover any such tendency. During the course of a complete review of the circuits, one possible cause of the difficulty was uncovered. This may be understood by referring to Figure 15. Figure 15 (a) shows the amplifier arrangement as initially configured. The circuit is a conventional one, with the cable shield returned to ground through a low value resistor to reduce effects of ground currents. On arrival at the NUC tower, the circuits were modified as in Figures 15 (b) and (c); note that for both of these modifications any current flowing the cable shield produces a voltage which adds to the signal input voltage. It appears that this source of data contaimination is the most likely cause of the anomalies in the data.

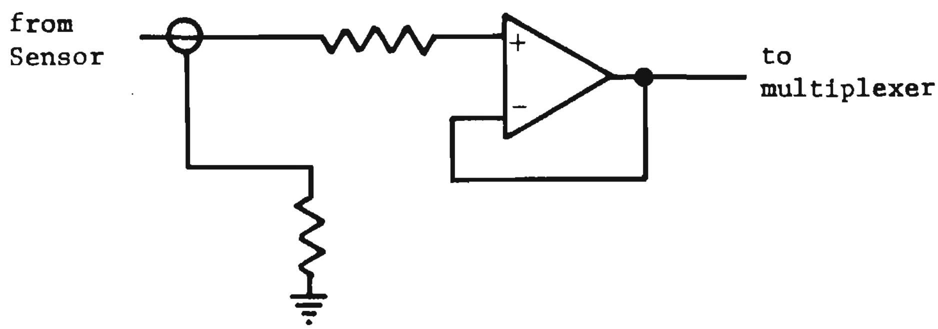
If these ground currents were constant for all of these inputs, a relatively constant input (such as the inclinometer) could be used to calibrate out the interference. Unfortunately each circuit was separate, and this was not found to be possible. It also appeared that the character of these currents varied from day-to-day, further complicating any attempts to calibrate out this interference. It appears that contamination other than negative "spikes" is present. Examination of tapes 14 and 15 (8/30 and 9/3) shows that though average values of the stripchart recordings and the digital data closely agree, some of the detailed fluctuations bear little resemblance to each other. However, there are other cases when the data appeared to be valid; in particular, wind data up to tape 21 appear reasonable.

C. Pulse-by-Pulse Data

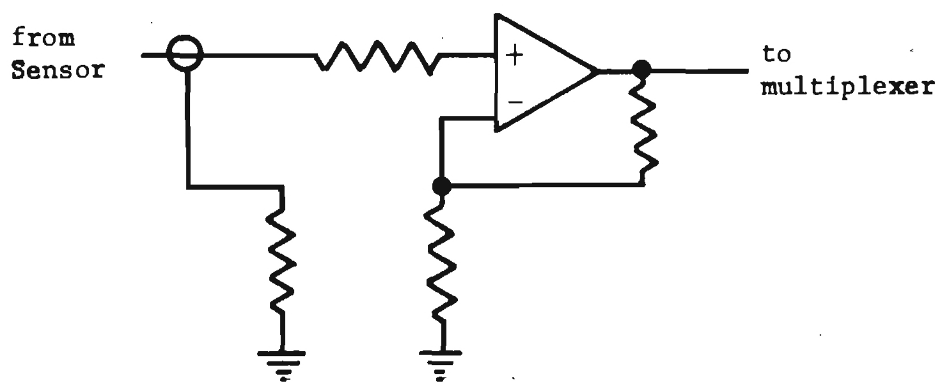
As mentioned earlier, the pulse-by-pulse data were primarily taken so as to more carefully define the behavior of the sea surface while average-value data were being taken. At the same time, these data provided additional data describing the frequency dependence of the sea clutter return and its upwind-downwind-crosswind behavior. On two occasions, at the request of DARPA, limited secondary experiments were performed to determine the detectability of "chaff" floating on the surface of the water. This experiment will be discussed first, followed by some observations on the behavior of the sea clutter return.



(a) Initial buffer amplifier configuration



(b) Buffer amplifier after modification for unity gain



(c) Buffer amplifier after modification for gain greater than unity

Figure 15. Environmental buffer amplifier configurations.

1. Surface Chaff Experiments

On two occasions, September 7 and September 21, measurements were made of the detectability of chaff and some styrofoam floats containing dipoles while floating on the water surface. The general conclusion to be drawn from this experiment is that the detectability was marginal; in fact, on 21 September, under conditions of moderately rough seas, the targets were never reliably detected. On 7 September (with wind speeds of approximately five knots) the detectability was somewhat improved and some worthwhile data were taken.

The data were acquired by pointing the antenna at the target using the telescopic sight and sampling on the target area and on adjacent sea clutter. These data were recorded and later reduced at EES, yielding both average values and distribution shapes.

The amplitude distributions of both the targets and the surrounding sea clutter appeared to be approximately log-normally distributed. Figure 16 shows the cumulative probability distribution of a data run for sea clutter at 16.5 GHz using horizontal polarization. Measurements were made at 9.5 and 16.5 GHz using both horizontal and vertical polarizations. The targets included a metallized fiberglass chaff which was spread on the surface of the water and several floats with dipoles in them. The floats were, not surprisingly, the more detectable targets, whether due to the styrofoam or the dipoles was not determined.

The chaff-to-clutter ratios were substantially larger at 16.5 GHz than at 9.5 GHz for all the measurements performed. Typical values on 7 September were 1-2dB at 9.5 GHz. and 10-17 dB at 16.5 GHz (for either horizontal or vertical polarizations), an observation which was confirmed by simultaneous A-scope observations. The chaff sank and dispersed rapidly under the influence of wind and waves; it was essentially undectable after 10-15 minutes.

While the 10-17 dB target-to-clutter ratios would be marginal for detection in log-normally distributed sea clutter with standard deviations of 5-7 dB, the rapid dispersal of the material, coupled with the lack of detectability under higher sea states such as encountered on 21 September,

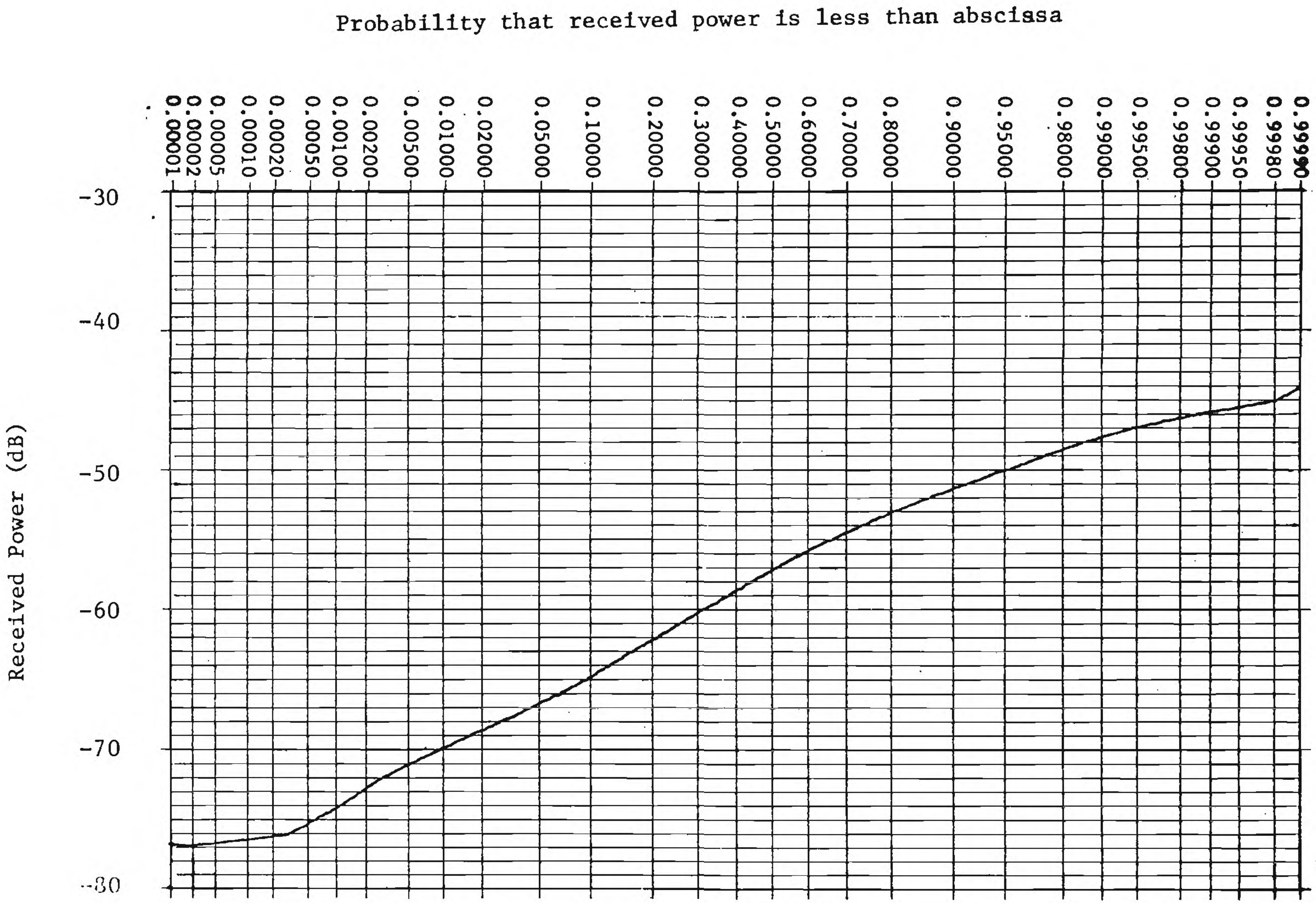


Figure 16. Cumulative sea clutter distribution.

makes the reliability of radar techniques for chaff detection questionable. This does not necessarily imply that different materials, or higher viewing angles, might not produce substantially different results.

2. Sea Clutter Characteristics

A number of measurements were made of the return from sea clutter during OWEX. These data were typically acquired from one range gate at each frequency or data set used. This was typically positioned near the center of the gates used to acquire average-value data. Occasionally either range or look direction was varied to determine the range or angle dependence of the sea clutter return. Most of the returns were approximately log-normally distributed, similar to Figure 16. These are of the class whose average received power lies approximately 3.5 dB below the 90% point of the cumulative distribution. Rather than using detailed amplitude distributions, much of these data were characterized by calculating the 50%, 90%, and 95% points of the cumulative distribution. The average received power was obtained by subtracting 3.5 dB from the 90% value, and the standard deviation in dB estimated by dividing the difference between the 90% and 50% points by a factor of 1.3. Radar cross-section per unit area, σ^o, was calculated from the average received power using measured values of antenna gain, beamwidth, transmitted power and system losses.

Table XI summarizes some sets of upwind, (U), crosswind (C), and downwind (D) measurements made on three different days. There are several interesting features of the data presented in Table XI. First, the general polarization dependence is the same as reported earlier, vertical polarization having a larger average cross-section than horizontal polarization. In general, the sensitivity of cross-section with look direction was larger for horizontal polarization than for vertical polarization. Second, the cross-section was largest in the upwind direction, as expected from earlier observations, but was asymetrical about the cross-wind/sea direction, and in fact sometimes has a minimum in the cross-wind direction. Third, the frequency dependence varied, σ^o for some runs increasing with with frequency and for some decreasing with frequency. It should be noted that these represent distributions calculated from approximately 40,000 data points.

TABLE XI

σ^o In dBm For Several Look Directions Relative To The Local Wind Direction. Range of 150 Meters and Depression Angle of 5.3 Degrees.

DATE	DIRECTION	σ^o 9.5 GHz HH	σ^o 9.5 GHz VV	σ^o 16.5 GHz HH	σ^o 16.5 GHz VV
8/21	U	-49.8	-34.7	-46.5	-43.1
8/21	C	-53.4	-36.7	-63.9	-44.1
8/21	D	-51.8	-34.2	-60.1	-41.4
8/26	U	-38.4	-25.2	-38.0	-31.9
8/26	C	-40.0	-27.2	-49.5	-33.3
8/26	D	-30.2	-27.2	-39.7	-34.0
8/27	U	-28.7	-22.9	-32.7	-30.1
8/27	C	-43.3	-28.8	-47.0	-34.7
8/27	D	-38.6	-26.2	-49.8	-35.9

Standard deviations in dB were also calculated for these runs and are presented in Table XII. Again, with the exception of 9.5 GHz data on 8/21, polarization dependence is much as reported by earlier investigations, horizontal having the larger standard deviation. It is interesting to note that there appeared to be a dependence of standard deviation with antenna look direction, particularly for horizontal polarization, with larger values obtained for the upwind/sea direction.

3. Calibration of Average-Value Data Sensitivity to Changes in Sea Clutter Return

In order to investigate the sensitivity of the average-value data to changes in average value of the sea clutter return, a brief analysis using the pulse-by-pulse data was undertaken. It was decided to approach the matter empirically, by use of actual recorded data, rather than analytically due to difficulties in accurately describing the sea clutter return mathematically.

The approach taken in this investigation was first to set up a transfer function between the pulse-by-pulse data recorded on tape and the output of the analog-to-digital converter. Then every tenth recorded value from a given channel or data set was read from tape, converted through the transfer function determined earlier, and a specified number of these values averaged. A given offset expressed in dB was then applied to the input data and the process was then repeated, in order to determine the sensitivity of the resulting averages to changes in average value of the sea clutter return.

The transfer function was determined in three stages. First, the calibration information was used to establish a transfer function between received signal strength (dBm) and signal recorded on tape. Second, data from Table III were used to map from dB referred to an arbitrary reference to fraction of output of the A/D converter excursion, and third a cubic least-mean-square fit was used to map from dBm to the fraction of A/D converter output excursion. The resulting coefficients were used to define a transfer function between signal recorded on tape and the fraction of A/D converter output excursion. The relationship between the power input and the fraction of the A/D converter output excursion was varied in order to represent changes in average value of the sea clutter.

TABLE XII

Standard Deviation in dB Assuming Log-normal Distribution for Several Look Directions Relative to Local Wind Direction. Range of 150 Meters and Depression Angle of 5.3 Degrees

DATE	DIRECTION	STANDARD DEVIATION (dB)			
		9.5 GHz		16.5 GHz	
		HH	VV	HH	VV
8/21	U	2.9	3.5	6.8	10.9
8/21	C	1.9	3.6	3.9	7.0
8/21	D	2.4	3.5	3.7	7.0
8/26	U	6.9	3.9	7.6	4.7
8/26	C	4.2	3.6	4.3	3.7
8/26	D	3.6	3.6	4.3	3.8
8/27	U	6.5	4.1	6.9	4.3
8/27	C	4.9	3.3	7.1	3.7
8/27	D	5.5	3.6	4.6	3.8

Data recorded on 24 September 1974 at approximately 11:52 were selected for analysis. It was found that sensitivity was a function of the averaging interval; specific averages were a function of the section of data reduced, but the sensitivity to changes (for a given number of data values averaged) was largely independent of the section of the data record analyzed.

The results for one-second averages and 10-second averages are shown in Figure 17. In addition, limited runs for 30-second averages were also performed but were indistinguishable from the 10-second averages (less than 0.01% difference). The sensitivities were somewhat different for the one-second averages and for the 10- and 30-second averages, as can be seen from Figure 17. It should be noted that these results may be transformed actual counts for a specific data run using procedures outlined in Section III-A.

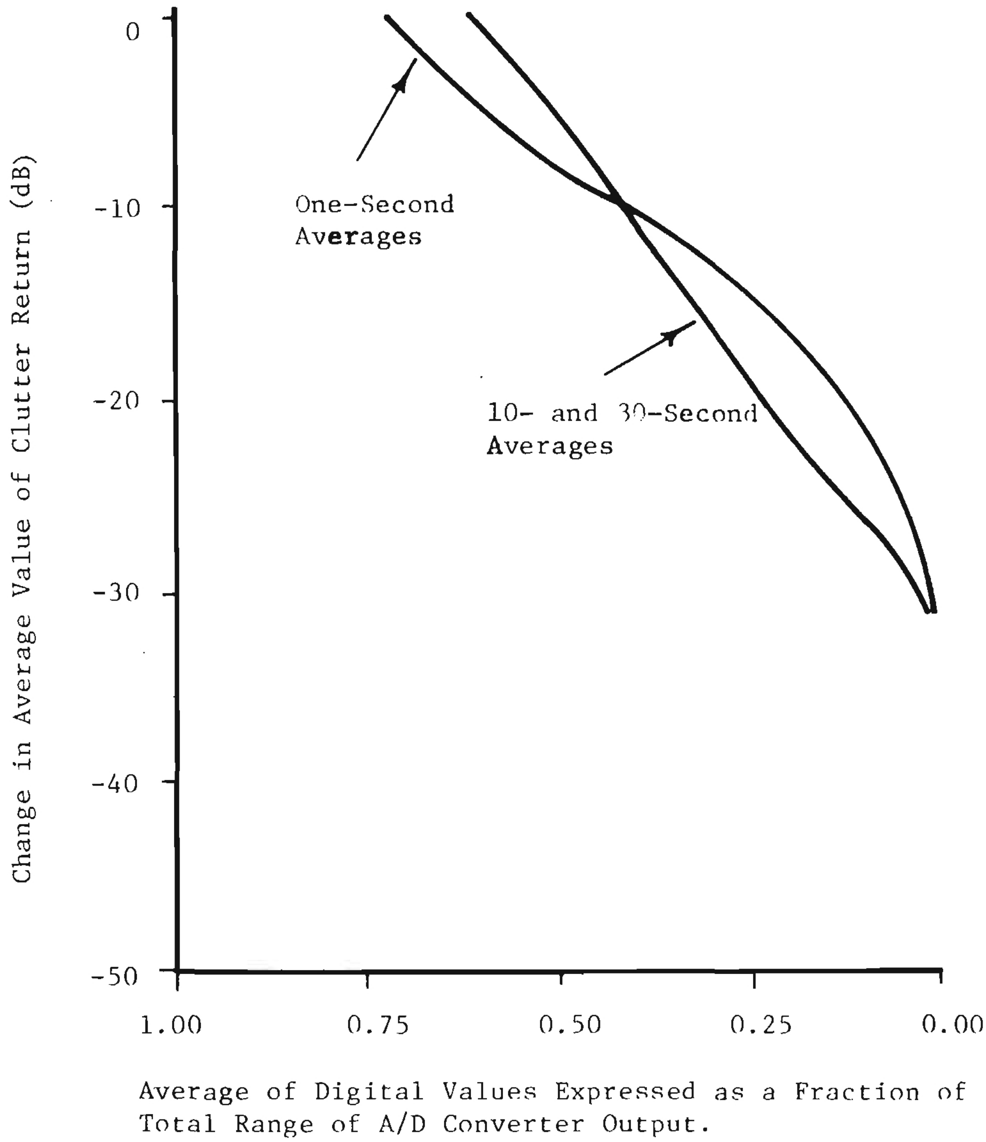


Figure 17. Change in the average of digital values expressed as the fraction of voltage excursion as sensed by the A/D converter for changes in average sea clutter level.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The radar sensors operating at 9.5, 16.5, and 35 GHz which were used for the OWEX proved to be a reliable and efficient method for acquiring data; over 200 hours of data were recorded during these tests, with no data acquisition time lost due to radar equipment malfunctions. Difficulties with magnetron spectra prevented any meaningful data from being taken with the 95 GHz measurement system.

The use of linear receivers (dictated by an extreme accuracy requirement) resulted in some saturation of the receiver. The resultant pulse stretching apparently produced some gate-to-gate coupling under conditions where appreciable saturation occurred.

Portions of the environmental data were contaminated due to circulating ground currents flowing in the shields of the interconnecting cables.

The absolute range calibration of the range gate locations varied from run-to-run due both to changes in geometry with look direction and to changes in firing time of the transmitters. Daily range calibration information is presented in this report, but some inconsistencies were observed when buoy ranges were measured.

The sea clutter behavior during most of these tests was similar in many ways to that reported by earlier investigators. The clutter return appeared to be log-normally distributed, horizontal polarization having a larger standard deviation than vertical polarization, but having a smaller average radar cross-section. There were pronounced dependances of sea clutter behavior on look direction relative to the local wind/sea, including a detectable variation in standard deviation with look direction.

The data acquisition program and equipment functioned reliably throughout the program. Some data tapes exhibited incorrect time at the beginning of the tape and difficulties with the parity error recovery routines. These tapes were copied at Georgia Tech and the errors corrected before being furnished to RDA, Inc., along with copies of all other data tapes and calibration information, for primary data analysis.

B. Recommendations

During the course of these experiments, several difficulties were encountered in data acquisition. These problems were of three general types; system hardware problems, data acquisition software problems, and operating procedures. Recommendations for improvement in these three areas are discussed in the following paragraphs.

1. System Hardware Recommendations - Several improvements, or changes in system hardware would substantially improve the data collection process: Specifically,

   a. The antenna beam patterns for the 16.5, 35, and 95 GHz systems should be modified in order to provide a more uniform return as a function of range.

   b. The use of wide-dynamic-range IF strips should be carefully considered. Such equipment would reduce calibration and saturation problems. The use of a high center frequency should be considered in order to reduce undesirable "tails" or signal stretching.

   c. The system losses at 35 GHz and the transmitter spectrum at 95 GHz should be improved.

   d. The delay reference for each channel should be derived from the generation of the rf pulse (probably from the magnetron current pulse).

   e. The gain factors for the environmental data channels should be adjusted to be more commensurate with the expected input voltages, and the input circuit modified to eliminate contamination of data by ground currents.

   f. The 60-Hz power source should be improved in order to provide a more stable and closely regulated source.

2. Data Acquisition Software Modifications - The software used to control the average value data acquisition could be improved substantially by:

   a. Incorporating the manually-entered "patches" into the program.

   b. Update time and run ID automatically on the "go" command given to the computer to ensure correct time and ID at the tape beginning.

   c. On-site capability to play back selected radar and environmental data should be provided.

d. The parity recovery routine should be corrected and carefully verified.

e. The on-line monitoring capability should be expanded to permit more than one data item to be monitored at one time.

3. Modification of Operating Procedures - The operating procedures should be modified so that

a. On-site playback should be used for initial checks throughout the experiment.

b. Complete raster plots should be generated on a daily basis using the EES programs on the NUC computer.

c. The range gate delays should be more accurately and regularly monitored throughout the experiment, preferably at hourly intervals.

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This report summarizes efforts carried out by the Engineering Experiment Station at Georgia Tech in support of the DARPA Ocean Wave Experiment (OWEX). The report concentrates on the radar equipment furnished for the experiment, and the characteristics of the resulting data. Detailed analysis of most of these data is not covered in this report, since this was handled by another organization.

This report first discusses the 9.5, 16.5, 35, and 95 GHz radars used during the experiment and the data acquisition systems used to record data.

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The data verification and calibration procedures are then discussed, and some representative data are reviewed. A portion of the data include some original observations concerning the upwind-downwind-crosswind behavior of radar sea clutter and representative sea clutter behavior for a range of environmental conditions. The report concludes with recommendations for improvements in both equipment and procedures for any future experiments.